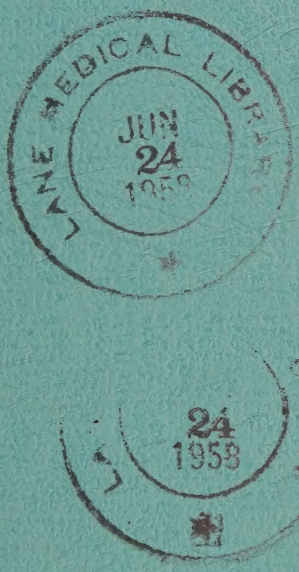
Leiden
1957
Lane

A pilot project of residual insecticide spraying in Netherlands New Guinea, contribution to the knowledge of holo-endemic malaria



D. METSELAAR

A PILOT PROJECT OF RESIDUAL INSECTICIDE SPRAYING IN NETHERLANDS NEW GUINEA, CONTRIBUTION TO THE KNOWLEDGE OF HOLO-ENDEMIC MALARIA

A pilot project of residual insecticide spraying in Netherlands New Guinea, contribution to the knowledge of holo-endemic malaria

PROEFSCHRIFT

TER VERKRIJGING VAN DE GRAAD VAN DOCTOR IN DE GENEESKUNDE AAN DE RIJKSUNIVERSITEIT TE LEIDEN OP GEZAG VAN DE RECTOR MAGNIFICUS Dr P. A. H. DE BOER, HOOGLERAAR IN DE FACULTEIT DER GODGELEERDHEID, TEGEN DE BEDENKINGEN VAN DE FACULTEIT DER GENEESKUNDE TE VERDEDIGEN OP WOENSDAG 6 FEBRUARI 1957 TE 15 UUR

DOOR

DIRK METSELAAR

GEBOREN TE ROTTERDAM IN 1914

DRUKKERIJ v.h. KEMINK EN ZOON N.V. — DOMPLEIN 2, UTRECHT

Promotor: Prof. Dr P. H. VAN THIEL

To
Tity F. M. J. Metselaar-van Sluys
this thesis is affectionately dedicated

VOORWOORD

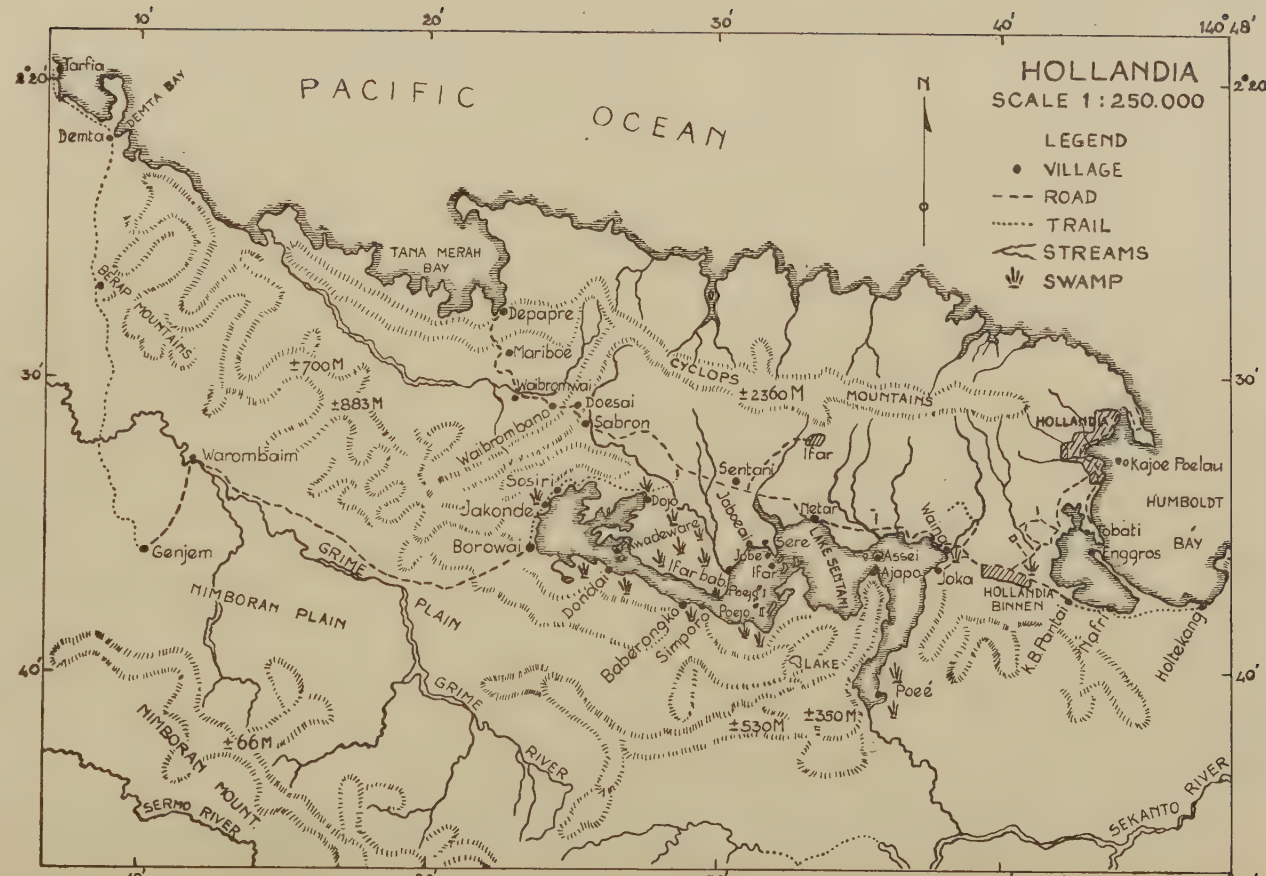
De gegevens in dit proefschrift verwerkt, zijn verkregen tijdens mijn werkzaamheden als hoofd van de Afdeling Malariabestrijding van de Dienst van Gezondheidszorg van Nederlands Nieuw Guinea. Voor de toestemming om van deze gegevens gebruik te maken ben ik dank verschuldigd aan de hoogedelgestrenge heer J. BIERDRAGER, directeur van deze dienst.

Van de leden van de staf van de Afdeling Malariabestrijding, welke mij allen met grote toewijding terzijde stonden, moge ik in het bijzonder noemen de heren M. VAN OS, hoofd van het laboratorium, en L. WANMA, oudste mantri.

De heer E. VAN LOO corrigeerde het Engels. De tekeningen werden verzorgd door de heer A. VAN DEN BROEK, het typewerk voor het manuscript door mejuffrouw W. KLOOSTERMAN, de typografie door de firma KEMINK EN ZOON.

CONTENTS

		Page
Introduction		1
Chapter I.	The vectors of malaria in New Guinea and their bionomics	8
Chapter II.	The experiment with window-trapped houses	27
Chapter III.	The field experiment	38
Chapter IV.	Observations other than strictly malariometric in the Lake- and Control Areas	79
Chapter V.	Classification of malaria	91
Chapter VI.	Discussion and prognosis	111
Summary		117
Samenvatting		121
References		125


HOLLANDIA
SCALE 1 : 250.000
LEGEND
VILLAGE
ROAD
TRAIL
STREAMS
SWAMP
N
PACIFIC
OCEAN
10'
20'
30'
40'
140°48'
2°20'
Tarfia
DEMTA BAY
Demta
TANA MERAH BAY
BERAP MOUNTAINS
±700M
±883M
Depapre
Mariboe
Waibrombai
Doesai
Sabron
Waibrombano
Warombaim
Sosiri
Jakonde
Genjem
Borowai
GRIME PLAIN
MIMBORAM PLAIN
GRIME RIVER
NIMBORAM MOUNT.
±66M
SERMO RIVER
CYCLOPS MOUNTAINS
±2360M
Ifar
Sentani
Doka
Jabea
Netar
Wadeware
Ifar bab
Poeio I
Poeio II
Dorialan
Babrongko
Simporo
LAKE SENTANI
LAKE
±530M
±350M
Poeé
Assei
Ajapo
Joka
Jobe
Sere
Ifar
Warna
HOLLANDIA
HOLLANDIA BINNEN
Kajoe Poelau
HUMBOLDT BAY
Tobati
Enggros
K.B.Pantai
Hafr
Holtekang
SEKANTO RIVER

"GENERALIZATIONS IN THE MALARIAL FIELD ARE NO MORE WARRANTED TODAY THAN THEY WERE YESTERDAY. . .". GIGLIOLI (1949).

INTRODUCTION

New Guinea is situated in the Australasian region between 130—152° East longitude and 0—12° South latitude, and therefore belongs to the real tropics. The island is divided by the 141st meridian into an eastern or Australian and a western or Dutch part. It is extremely sparsely populated, density in the Dutch part being on an average no higher than three per km^2. There is a central mountain range with altitudes up to 5000 metres with mountains and marshy plains alternating between this and the coast. The lower altitudes are as a rule highly malarious. In the Australian part of the island, malaria has also been reported from altitudes up to 1700 metres (Minj Conference, personal communication). However in Netherlands New Guinea there are indications that the climate at those altitudes is less favourable for transmission of malaria. In the Wissel Lake area (1700 metres) no anophelines have been encountered so far. In the Baliem Valley (1700 metres) *A. farauti* abounds, but transmission has still to be proved. Transmission of malaria is perennial in the island, apart from areas in the south, where between May and October a dry season temporarily prevents the breeding of mosquitoes.

The main vectors are three members of the *Anopheles punctulatus* group, viz. *A. punctulatus, A. farauti* and *A. koliensis,* while locally *A. bancrofti, A. karwari, A. amictus hilli* and *A. subpictus* may play a part.

After the successful introduction of residual insecticide spraying in malaria control in several parts of the world, there has been a tendency to believe that study of the bionomics of local vectors of that disease was not longer necessary. However, this view appeared to be too optimistic and it was GIGLIOLI who in 1949 pointed out that measures of malaria control, whether by means of residual insecticides or by older methods, cannot be effective or economically sound unless they are applied with a thorough knowledge of local epidemiological conditions. Especially bionomics of adult insects must, according to this author, be thoroughly understood.

This statement was made because it became apparent about that time that not all mosquitoes reacted in the same favourable way to the application of residual insecticides to the inner walls of buildings. It appeared that some species of anophelines have the natural habit of avoiding contact with inner walls of houses, irrespective of whether these are covered with insecticides or not. During the time when malaria control implied larval control, not much attention had been paid to this property. Only when pyrethrum space-spraying began to be practised in some countries was its importance revealed.

To simplify the study of adult anopheline behaviour in this respect, SENIOR-WHITE (1954) proposed a classification which distinguishes two types of mosquitoes as regards resting- and two as regards feeding-habits. He distinguishes:

endophily, the habit of remaining in man-made shelters during the whole or a definite part of the gonotrophic cycle;

exophily, the habit of remaining out of doors during the greater part of the gonotrophic cycle;

endophagy, the habit of obtaining the blood-meal inside man-made structures;

exophagy, the habit of obtaining the blood-meal out of doors.

Of course, intermediate classifications are possible between the two extremes: endophilic-endophagic and exophilic-exophagic; for instance, many mosquitoes are known which are optionally endo- and exophylic.

It is obvious that diseases transmitted by insects that are both distinctly exophylic and distinctly exophagic cannot respond favourably to indoor spraying with insecticides. The most important malaria vectors in New Guinea and adjacent islands have long been believed to belong to this extreme category. It was accepted that, as a rule, these anophelines did not enter houses for their blood-meal. And when, on rare occasions, some mosquitoes managed to do so, it was believed that they never touched the wall, but came in, sucked blood, and left. For several years this conviction has delayed the large-scale application of residual insecticide spraying as a means of controlling malaria in the south-west Pacific area.

None the less, there had been several observations which might have aroused doubt whether feeding and resting of anophelines of the *punctulatus* group really occurred so strictly out of doors. HEYDON (1923), referring to *A. moluccensis* (= *A. farauti*) and *A. punctulatus* at Rabaul, New Britain, writes "Both frequent houses, where the female bite throughout the night and can be found during daytime, ...". American entomologists, working in the Solomons and New Hebrides during the second world war, unanimously confirm these facts. BELKIN et al. (1945) state: "Adult females (*A. farauti*) enter any type of shelter; .... resting blooded females may be collected at will in occupied houses and native huts....". Similar statements are made by PERRY (1946, 1949) and DAGGY (1945). It may be that, in the islands of the eastern part of its distribution area, *A. farauti* is more endophilic, as observations by BLACK (1954) would suggest, but also on the mainland of New Guinea several authors observed not only females of that species, but also of *A. punctulatus* and *A. koliensis* entering human dwellings at night for their blood-meal, while some of them appeared to stay there by day, resting on walls or all sorts of objects (BANG et al., 1947; ROBERTS & O'SULLIVAN, 1948; SWELLENGREBEL & STACK, 1949; DE ROOK, personal communication).

Small-scale trials with DDT had been made during and shortly after the war. YUST (1947), in the New Hebrides, reported that 5 per cent. DDT residual spray, applied to native huts, controlled *A. farauti* for three months; but the breeding places were also treated. An unpublished U.S. Army report quoted by ROBERTS & O'SULLIVAN (1948) speaks of encouraging results in Salamaua, where the three main species of *A. punctulatus* occur. SWELLENGREBEL & STACK (op. cit.) sprayed a few houses near Sentani Lake with DDT in kerosene, but obtained inconclusive results. BANG et al. (1947) sprayed a village in the southern part of Australian New Guinea 150 miles west of Port Moresby, where *A. farauti* and *A. subpictus* were the prevalent anophelines, using 4 per cent. DDT in kerosene at a rate of 100 mg per square foot. After four months the parasite rate had slightly decreased, while the spleen rate remained the same. In an untreated control village both had increased.

On the other hand, several authorities, not convinced that members of the *Anopheles punctulatus* group would enter man-made structures in sufficient number or would stay there for a sufficiently long period, expressed considerable reserve as to their expectations of the results of residual insecticide spraying in areas where these vectors are responsible for malaria transmission (SWELLENGREBEL, 1948a; FORD, 1950; BIERDRAGER & DE ROOK, 1954).

In this situation a large-scale experiment seemed necessary — a necessity emphasized at the First Asian Malaria Conference held at Bangkok in 1953 — to establish more definitely the value of residual insecticide spraying in New Guinea and adjacent islands, where malaria has been the main cause of the poor development of many aspects of human life, and the most serious obstacle to what may be regarded as a reasonable prosperity.

The description of such a pilot project, and the observations of its results during two years, constitute the main subjects of this publication. However, the investigations carried out in connection with this pilot project to collect basic epidemiological information, revealed some interesting aspects of malaria in New Guinea which may be of more than merely local importance. The Malaria Conference for Equatorial Africa held at Kampala, Uganda, proposed a working classification for malaria endemicity, which is based only on the course of the spleen rate in relation to age (WHO, 1951). This classification starts from the assumption that, in regions where the highest degree of malaria endemicity prevails, the spleen rate, because of developing immunity, necessarily goes down with increasing age. Surveys revealed, however, that this highest degree of malaria-endemicity is encountered in Netherlands New Guinea, but without the decreasing spleen rate with increasing age. Considerations regarding the possible causes of this divergence from what has been observed elsewhere, are other subjects of this thesis.

Health conditions in Netherlands New Guinea have been described recently by BIERDRAGER & DE ROOK (op. cit.), and VAN DER HOEVEN (1956).

It therefore seems superfluous to enlarge once more on the subject. As far as necessary for a right understanding, the health conditions encountered in the experimental areas will be discussed in Chapter III.

As regards the nomenclature of the anophelines of the *punctulatus* group, a few words of clarification for those not familiar with these mosquitoes may be of value. For many years those mosquitoes of the group in which the apical third of the proboscis is white, have been designated *A. punctulatus* Dönitz, while the name *A. punctulatus moluccensis* Swellengrebel and Swellengrebel covered a variety of which the members showed either an entirely dark proboscis — excluding the labella —, or a proboscis with a pale ventral area on the apical quarter, which pale area varies greatly in extent, and sometimes even encircles the dorsum of the proboscis. In 1944 KNIGHT & FARNER drew attention to the fact that the *moluccensis* variety rightly deserved the name *A. farauti* Laveran. Not long afterwards OWEN (1945) separated the variety with the pale patch on its proboscis from that with the entirely dark one, naming the former *A. koliensis* and reserving the name *A. farauti* for the latter. Thereupon BELKIN, KNIGHT & ROZEBOOM (1945) proposed to give the three varieties the status of species. Finally ROZEBOOM & KNIGHT (1946) described a new species which they named *A. clowi.*

WOODHILL (1946) is of the opinion that *A. farauti* and *A. koliensis* do not deserve the status of a species. He regards *A. farauti* as a sub-species of *A. punctulatus,* and *A. koliensis* — presumably also *A. clowi* — as a hybrid of the two. Australian workers therefore refer to the latter as "intermediates". The problem still awaits solution. In the present publication the nomenclature proposed by BELKIN et al. (op. cit.) will be used. As it is often doubtful whether *A. farauti* or *A. koliensis* is referred to when the name *A. moluccensis* is used in the older literature, the latter name will be reserved for such cases.

Since HODGKIN (1950) pointed out that only the sporozoite rate of mosquitoes dissected shortly after capture, is a valuable indication of the risk of infection to which a population is exposed, we shall refer to sporozoite rates only in the following chapters and neglect records on oocyst-positive mosquitoes. In our laboratory, time-consuming gut dissections have rarely been done. The great majority of the dissections which will be recorded in the next chapters were done in the field within 12 hours after the catch, by cutting the head of the mosquito and pressing out part of the contents of the thorax on a slide (method Sergent). The slides were then Giemsa-stained. These "thoracic juice slides" were examined later on at Hollandia Binnen. In June 1955 gland dissections replaced Sergent's method.

The precipitin reactions to discover the origin of the gut contents of the anophelines caught in the Nimboran, the results of which are recorded in Chapter I, were performed in the Laboratory of Parasitology of Prof. van Thiel at Leyden.

We may also note at this point that members of the *punctulatus* group are important vectors of filariasis.

A brief description of the organization of the Malaria Control Service of Netherlands New Guinea will make it clear that during 1953, 1954 and 1955 a choice had often to be made between almost equally urgent research, control, and educational work. The Service is a Division of the Public Health Service of Netherlands New Guinea. The other Divisions are the Division for Mother and Child Health, the Yaws Control Division, the Leprosy Control Division, and the Tuberculosis Control Division. The Division of Malariology came into being in 1950. Its headquarters are set up in Hollandia Binnen, the capital of Netherlands New Guinea. Its responsibilities cover the whole of the territory and must therefore be partly transferred, outside Hollandia, to the local medical officers. The Head of the Service is responsible to the Director of Health.

When I took over the conduct of the Service at the end of 1952 there was:

a small and primitive laboratory,

1 qualified sanitary inspector,

1 qualified native technical assistant (mantri), trained for laboratory and field work,

2 supervisors and a number of natives for oiling breeding places,

1 driver,

no administrative staff.

Sufficient laboratory equipment of good quality soon became available, while with the help of the Institutes of Tropical Medicine at Leyden and Amsterdam, a small but useful library was set up.

Outside Hollandia only one qualified native technical assistant was posted, i.e. at Manokwari.

Early in 1953 one administrative clerk was appointed, and a three-year training course for native technical assistants was started. A second course followed in 1954, and a third in 1955. Of the first class only one pupil qualified in 1955. The pupils of the following classes having a better basic school education, were of a higher average quality. All of them could soon be used for various types of field- and laboratory work. The Papuan pupils were ambitious and generally speaking, one could rely on them. During 1953 and 1954 it was possible to carry out a considerable amount of work with this small and insufficiently trained staff. The constant help of my wife in the laboratory and in the field has also been extremely valuable.

In April 1955, after the old laboratory was destroyed by fire, we put into use a new, suitable, though still temporary, laboratory. In the course of 1955 the staff was extended more rapidly and was joined by a second

physician and two administrators, while in 1956 an entomologist was engaged. In April 1956 the Hollandia Staff was composed as follows:

1 senior malariologist,
1 malariologist,
1 entomologist,
1 sanitary inspector, head of the laboratory,
8 qualified native technical assistants,
3 native apprentice technical assistants,
1 senior administrator,
2 administrators,
1 native clerk,
1 driver,
3 supervisors of DDT spraying squads,
a number of native sprayers.
Outside Hollandia:
1 qualified native technical assistant,
3 supervisors of DDT spraying squads,
a number of native sprayers.

So far the coming to New Guinea, for a six months' stay, of Professor and Mrs. van Thiel has not yet been mentioned. The importance of this fact for our Service could hardly be overestimated. Before their arrival nobody on the staff had any experience in research work in the field of malariology. When they left in March 1954, valuable information was gained concerning the bionomics of adults of the *Anopheles punctulatus* group and about their reactions to insecticides, and the pilot project had got definite shape.

Part of this project consisted of trials with window-trapped houses to obtain more information on the feeding and resting habits of the local anophelines. Later on two of the three houses were sprayed with DDT and dieldrin respectively. The other part of the project included a large-scale field trial with an experimental area for DDT on and around Sentani Lake and a control area in the Nimboran Valley. It was decided to use DDT because the qualities of this insecticide were best known at that time. After one year of observation, the Nimboran also became an experimental area, this time to evaluate the influence of residual spraying with dieldrin on malaria transmission.

The results of the observations regarding feeding and resting habits of the local anophelines in the window-trapped houses, including those of an observation period of six weeks after the insecticide application in these huts, have already been published (VAN THIEL & METSELAAR, 1954, 1955).

The Malaria Division had regular contacts with the World Health Organization, particularly with the Malaria Adviser for the Western Pacific Region, Dr. F. J. DY, who twice visited Netherlands New Guinea and obliged us with valuable advice. I attended with no little profit the

WHO Malaria Conferences at Bangkok and Baguio, while this organization awarded me a useful travel-fellowship of 2½ months duration in countries of South East Asia.

Since 1955, UNICEF has provided valuable assistance in the form of insecticides, sprayers, transport and laboratory equipment.

The Public Health Service of Australian New Guinea organized a New Guinea Malaria Conference at Minj in February 1954, at which it was decided that our Australian colleagues would supplement the researches done in Netherlands New Guinea by a pilot project in which dieldrin would be used. However, the implementation of this plan met with difficulties, and because later on the qualities of dieldrin became better known from the literature, I decided to extend the Sentani pilot project, and to spray the Nimboran area with dieldrin. Two members of the staff of the recently organised Malaria Control Service of Australian New Guinea visited Hollandia and our pilot project.

Dr. E. MASSAL, Dr. M. O. T. IYENGAR and Dr. H. A. P. C. OOMEN, all staff members of the South Pacific Commission, and Dr. R. H. BLACK, with a S.P.C. mandate, were among our distinguished guests. They all helped the Malaria Division with their extensive knowledge of tropical medicine and hygiene.

CHAPTER I

THE VECTORS OF MALARIA IN NEW GUINEA AND THEIR BIONOMICS

A. The Anopheles punctulatus group

a. *Breeding places*

The three most important members of the *punctulatus* group, viz. *A. punctulatus, A. farauti* and *A. koliensis* are very indiscriminate in the choice of their breeding places. When the water surface is sunlit, they breed almost anywhere (Heydon, 1923; de Rook, 1924; Belkin et al., 1945; Daggy, 1945; Perry, 1946; Mauzé, 1946; Laird, 1946 a and b; Horsfall & Porter, 1947; Yust, 1947). Nevertheless some behaviour differences can be observed.

A. punctulatus prefers fresh, temporary rainpools, like wheelruts, roadside ditches, footprints, hoofprints, usually exposed to maximum amounts of sunlight. These breeding places are usually devoid of vegetation; they are frequently muddy, but never foul. Brackish water is avoided. However, in coastal plains and in periods of heavy rains, this species may share its breeding places with *A. farauti*. Larvae have been collected also from the edges of small streams, but less often than those of *A. farauti*.

A. punctulatus is extremely well adapted to its temporary breeding places. After hatching, it completes its aquatic cycle very rapidly: less than 8 days (Belkin et al., op. cit.), 6½ to 9 days (Laird, 1946b) or, according to Horsfall & Porter (op. cit.), even in 6 days. Belkin et al. (op. cit.) and Horsfall & Porter (op. cit.) suppose that eggs may be laid on mud. Under such conditions they should be viable for fourteen days in which time they develop but do not hatch until the breeding place is flooded.

After a temporary pool, which had been dry for two days, was filled with water, Belkin et al. (op. cit.) observed also living fourth instar larvae and pupae emerging from the mud. De Rook (personal communication) noticed the same at Pioniersbivak. Bick & Penn (1947) saw *A. punctulatus* larvae survive for 120 hours on damp filter paper in Petri's dishes flooded for 30 minutes at 24 hours intervals. We ourselves observed a number of fourth instar larvae which had been kept for 36 hours on wet filter paper in a Petri dish crinkle away after the dish was filled with water. They pupated soon afterwards.

In their favourite habitats *A. punctulatus* larvae can also stand relatively

great temperature changes, and high temperatures, sometimes up to 41° C (LAIRD, 1946b).

By the nature of its breeding places, which are often man-made, this species may vary greatly in abundance.

Larvae of *A. farauti* and *A. koliensis* are collected mainly from longer established water collections or permanent pools, like swamps, along banks of rivers, taro-gardens, ditches, wells etc. This type of breeding places is practically always provided with vegetation and may therefore be somewhat shaded at times. *A. farauti* does not avoid brackish, or sometimes even almost briny, water. In periods of abundance, on the other hand, it can be found in breeding places typical for *A. punctulatus*. Its aquatic cycle is slightly longer than that of the latter species (LAIRD, 1946b).

The variations in abundance of *A. farauti* and *A. koliensis* are less marked than of *A. punctulatus*.

All three species prefer "soil-surrounded" breeding places, and are collected only occasionally from tins, drums, coconut shells, etc. They have never been found in axils of plants, and only once in a rot hole in the limb of a tree (LAIRD, 1946a).

With regard to malaria control by means of residual insecticides, the bionomics of adult anophelines are still of more importance than those of larvae. Attention must be given to biting, feeding and resting habits; to abundance, longevity, susceptibility to infection and sporozoite rates; to duration of the development of the malaria parasite in the insect host (extrinsic cycle), and to the duration of the gonotrophic cycle. These items will be discussed in the following paragraphs.

b. *Biting habits*

In its biting habits the preference of the mosquito for man or animal as a source of blood finds expression. It can certainly be best estimated by the precipitin test on the gut contents of specimens which, in the case of anophelines of the *punctulatus* group, must be collected from outdoor resting places. However, records of such tests regarding these anophelines are scarce. Those published up to 1947 have been summarized by MACKERRAS (1947). I quote him and add a few personal observations (Nimboran I and II) in Table I. The rates in that table recorded from Milne Bay and Lalapipi, and that of the first Nimboran series, concern mosquitoes which were collected in the bush around native villages. In the Cairns series a small number of mosquitoes from inside houses were included. The second Nimboran series was entirely collected indoors. It should be mentioned that, in the particular village where our collections were made, practically no pigs were bred.

The figures are small and do not allow of any definite conclusions. Those of *A. punctulatus* point to the fact that this species is probably highly anthropophilic in the areas where the catches were made, while

TABLE I

BLOOD SOURCES OF ANOPHELINES OF THE PUNCTULATUS GROUP.

Results of precipitin tests.

Species	Locality	Collectors	Number	Per cent. human blood	Remarks
A. punctulatus	Milne Bay, New Guinea	Aberdeen & Brasher	37	95 %	Others: + dog, + cat
	Milne Bay, New Guinea	Bayley	50	94 %	Others: + dog
	Nimboran Valley I, New Guinea	Metselaar	34	85 %	Others: + dog
	Nimboran Valley II, New Guinea	Metselaar	23	78 %	Others: unknown
A. farauti	Lalapipi, New Guinea	Atherton & Lemerle	88	19 %	Others: + dog 47 %
					+ pig 33 %
					+ cat 1 %
	Cairns, Australia	Roberts & O'Sullivan	81	9 %	Others: + fowl 37 %
					+ ruminants 26 %
					+ horse 22 %
					+ dog 6 %
	Nimboran Valley I, New Guinea	Metselaar	6	83 %	Others: + dog
	Nimboran Valley II, New Guinea	Metselaar	6	66 %	Others: unknown
A. koliensis	Nimboran Valley I, New Guinea	Metselaar	15	60 %	Others: + dog

A. farauti seems to be more indiscriminate in the choice of its blood-meal, and in all probability selects the most readily available host. In the laboratory too, *A. punctulatus* was more easily persuaded to take a blood-meal on man than *A. farauti* (MACKERRAS & ROBERTS, 1947).

Exceptions to the rule probably occur; for BELKIN et al. (op. cit.) at Guadalcanal, in areas where there was little chance for human contact, found larvae of *A. farauti*, the imagoes of which, when reared in the laboratory, were distinctly reluctant to feed on man. This, in the opinion of the authors, might indicate the presence in Guadalcanal of a "wild" strain of *A. farauti*. In the same island the same authors could collect only relatively few *A. punctulatus* on human baits and in human dwellings, even in areas of high larvae density. Though females of this species collected there fed readily on man in captivity, the finding might suggest that *A. punctulatus* loses much of its affinity for human blood in the eastern part of its distribution area.

A. koliensis is, according to BELKIN et al. (op. cit.), a highly anthropophilic species. The few precipitin tests of my Nimboran I series agree with this statement.

c. *Feeding habits*

As regards the feeding habits of the three species under consideration, it has already been stated in the introduction that a survey of the literature compelled the conclusion that the view that anophelines of the *punctulatus* group are distinctly exophagic cannot any longer be held. The observations by VAN THIEL & METSELAAR (op. cit.) in experimental huts likewise showed that they readily enter houses for their blood-meal.

In one experiment described by these authors, mosquitoes were given the choice between one boy serving as human bait inside an open hut and another boy sitting outside. About 30 per cent. of the anophelines which came for a blood-meal entered the hut. *A. koliensis* showed even preference for doing so. Biting continued throughout the night.

In another (unpublished) experiment of this type, one human bait was situated near the three experimental huts. At the same time a second boy was collecting mosquitoes in one of these huts, of which door, windows and eaves were kept open. Door and windows of the two other houses were closed, so that mosquitoes could enter through the eaves only. In each of the latter two huts three boys were placed. Between 7 p.m. and 11 p.m. the boy outside the houses was attacked by 69 anophelines, the one in the open house by 54, while in each of the almost closed houses respectively 18 and 45 anophelines were collected. This experiment may be regarded as approximating more nearly to the usual situation in the evening in many native villages of New Guinea. It shows that many mosquitoes take the trouble of entering a relatively inaccessible house, even when another source of human blood is more easily available nearby.

The fact that activity goes on throughout the night had already been

observed at Salamaua by ROBERTS & O'SULLIVAN (op. cit.), who attempted all night catches on human baits both indoors and in the open. On the two occasions and for the three species they found a gradual increase during the early hours of the night, becoming most prevalent between midnight and 3 a.m. In Hollandia Binnen, all-night catches were held in the night from 23 to 24 October 1953. Two boys collected from sunset to midnight, i.e. one indoors and one in the open. At midnight they were replaced by two other boys. The results are summarized in Table II A and B. Records of *A. karwari* are included. Later on, in 1955, eight all-night catches were organized in the Nimboran Valley, this time outside only. The results are summarized in Table III. *A. karwari* was hardly

TABLE II
NOCTURNAL PREVALENCE, HOLLANDIA 23-24 OCTOBER 1953.

	6.30–7 pm	7–8 pm	8–9 pm	9–10 pm	10–11 pm	11–12 pm	12–1 am	1–2 am	2–3 am	3–4 am	4–5 am	5–6 am
A. One man catching out of doors												
A. punctulatus	0	4	2	8	2	2	1	0	2	2	3	2
A. farauti	5	22	25	21	22	19	10	1	11	11	9	7
A. koliensis	0	14	7	11	9	10	5	8	13	12	7	4
A. karwari	0	0	1	0	0	1	1	0	15	19	15	13
Total	5	40	35	40	33	32	17	9	41	44	34	26
B. One man catching indoors												
A. punctulatus	0	0	1	0	0	0	3	3	2	3	0	0
A. farauti	1	2	4	7	4	5	1	2	0	0	1	0
A. koliensis	2	2	10	5	10	5	9	8	4	2	3	2
A. karwari	0	1	0	1	0	4	5	6	7	7	4	0
Total	3	5	15	13	14	14	18	19	13	12	8	2

TABLE III
NOCTURNAL PREVALENCE, NIMBORAN VALLEY.
Results of 8 catches in the open, on one man.

	6.30–7 pm	7–8 pm	8–9 pm	9–10 pm	10–11 pm	11–12 pm	12–1 am	1–2 am	2–3 am	3–4 am	4–5 am	5–6 am
A. punctulatus	4	37	41	43	33	29	19	19	12	4	5	3
A. farauti	0	6	9	13	7	7	2	7	7	2	1	2
A. koliensis	3	16	18	18	25	13	7	2	4	3	3	2
Total	7	59	68	74	65	49	28	28	23	9	9	7

Six of the eight nights were dry, on two nights there was occasional rain.

collected at all in the Nimboran at that time and is omitted from the table. Unlike the findings of ROBERTS & O'SULLIVAN, our tables show a maximum of activity in the early hours of the night, which, in the outdoor catch at Hollandia, is followed by a second wave between 2 a.m. and 4 a.m.

Naturally, however, it will rarely happen that people are in the same spot, either in the open or indoors, from sunset to dawn. In another series of catches, therefore, the boys imitated the local people, sitting outside the house or on the gallery when these did, and then collecting indoors when the others went inside to sleep. They had strict instructions to collect mosquitoes on their own bodies only. Two boys collected from sunset to midnight, two others from midnight to dawn. Every night another village or another house was chosen. In total eight boys worked in turn, thus eliminating the factor of personal attractivity. Unfortunately, on nights when mosquitoes were abundant they could not all be caught, while several nights in a dry period yielded only very few anophelines. All collections on these occasions are omitted from the series, after which there remained 23 nights of moderate mosquito prevalence. The results are summarized in Table IV. The difference between the highest average

TABLE IV
NOCTURNAL PREVALENCE, NIMBORAN VALLEY.
Results of 23 "all-night" catches, two men catching at the same time, and imitating local people's habits.

	6.30–7 pm	7–8 pm	8–9 pm	9–10 pm	10–11 pm	11–12 pm	12–1 am	1–2 am	2–3 am	3–4 am	4–5 am	5–6 am	Total 2 men
A. punctulatus	22	46	58	67	60	59	68	77	64	58	52	41	672
A. farauti	6	24	36	34	47	29	21	18	33	16	11	23	298
A. koliensis	30	70	62	64	78	65	64	49	49	49	46	43	669
Total	58	140	156	165	185	153	153	144	146	123	109	107	1639
Average	2.5	6.1	6.8	7.2	8.0	6.7	6.7	6.3	6.3	5.3	4.7	4.6	71.3

hour-catch (10—11 p.m.) and the lowest (5—6 a.m.) is not more than twice the standard error of difference. It may therefore be concluded that on an average the population in the Nimboran Valley risks being bitten by anophelines practically equally all night long.

A number of daytime biting records have been obtained. In most cases these attacks happened in covered or shaded areas or when the mosquitoes were disturbed (ROBERTS & O'SULLIVAN, op. cit., BELKIN et al., op. cit., PERRY, 1946). HEYDEN (1923) never saw it, the present author only once. SWELLENGREBEL & STACK (1949), on the other hand, fear that this daytime biting habit may be of some importance in the transmission of malaria.

d. *Daytime resting places*

On entering human dwellings for a blood-meal most mosquitoes will

rest for a while, maybe before or after the feeding. In the Nimboran empty anophelines were observed up to 110 minutes, and engorged females up to 50 minutes, sitting at night on the inner walls of a village house where natives were sleeping. Most anophelines, however, leave again in the course of the night to look for daytime shelter out of doors. VAN THIEL & METSELAAR (op. cit.) showed in their experiment that this tendency to leave is most marked towards daybreak, and that only a minority used the experimental hut as a daytime resting place (12.3% of 1607 anophelines).

In the outdoor resting places mosquitoes are often difficult to find, which is not surprising, since GILLIES (1955) calculated that at most a few score of anophelines can be expected to occur per acre of bush. Our staff had only an occasional success when looking for anophelines in possible outdoor daytime shelters. Others (ROBERTS & O'SULLIVAN, op. cit., BELKIN et al., op. cit., BLACK, personal communication; HORSFALL & PORTER, op. cit.) obtained better results and captured females of *A. farauti* in moist places near the ground in the trash of banana trees, on buttressed tree trunks, on long grass stems and ferns, along banks of streams and other places of high humidity.

The tendency to select human dwellings as daytime resting places seems to be strongest in *A. koliensis*; 90% of the anophelines collected by day from inner walls by BELKIN et al. (op. cit.) belonged to this species. In the experiment by VAN THIEL & METSELAAR (op. cit.), out of 557 *A. koliensis* that entered a hut during a number of nights, 104 (19%) could be collected the following morning on the inner walls. These figures are for *A. punctulatus* 53 (18%) out of 300, for *A. farauti* 6 (4%) out of 144, and for *A. karwari* 12 (9%) out of 136. The differences between the first two and the others are significant.

Apparently, anophelines of the *punctulatus* group rarely leave the house with ripe ova (VAN THIEL & METSELAAR, op. cit.). Practically all anophelines encountered on the inner walls by day are freshly engorged, and stay there until the following night only, when they leave to complete the gonotrophic cycle in outdoor resting places.

e. *Flight range*

With regard to flight range, only a few observations are recorded. In the New Hebrides, DAGGY (1945) observed *A. farauti* 600 yards offshore. At Salamaua, isolated females of this species were not uncommon in huts on an isthmus about one mile from the nearest breeding place (ROBERTS & O'SULLIVAN, op. cit.). At Sorong, catches of *A. punctulatus* and *A. farauti* at a catching station did not become negative until breeding places at 1½ miles distance had been treated with oil (DE ROOK, personal communication), at Oro Bay at a distance of three quarters of a mile (HORSFALL & PORTER, op. cit.). At Tanah Merah, DE ROOK (1929) re-captured a single marked *A. punctulatus moluccensis* at a distance of 2400 metres from the place where about 150 specimens of this species were released.

f. *Abundance*

Several of the authors already cited above make mention of the large number of the three species that sometimes attack man. Our human baits could at times collect 30 or more anophelines per man per hour on their own legs.

g. *Longevity*

Regarding the longevity of the three species in nature, no direct observations were made. In colonies *A. punctulatus* survived longer than *A. farauti* (MACKERRAS & ROBERTS, op. cit.).

h. *Sporozoite rate*

Records of sporozoite rates of anophelines of the *punctulatus* group collected under natural circumstances of endemicity are extremely scarce. Most dissections were done during war epidemics among troops, or in areas where control measures were in operation and prophylactic drugs were used by troops. When the mosquitoes were captured near native villages, these villages were often situated in regions where the war had recently greatly disturbed normal native life, as in the series of MACKERRAS & ABERDEEN (1946). The records are summarized in Table V. Some are derived from MACKERRAS (1947). A number of personal new series are added. Details of the latter will be discussed more fully in para. k and in Chapter III. From the table it will be seen that only in two cases does the percentage of positives in the *punctulatus* group exceed 2.5%, i.e. that found by HEYDON and that found by ABERDEEN. The former, however, in a personal communication to BANG & HAIRSTON (1947) states that his figure cannot be regarded as reflecting the general rate in nature, because he kept the mosquitoes in captivity for several days before dissection. Of ABERDEEN's dissections nothing is known to me except that the number is small and that they most probably date from wartime. As a rule, the sporozoite rates are only moderately high and do not approach such values as are often recorded from, e.g. *A. gambiae* in Africa. The total of my series comprises 3896 anophelines of the *punctulatus* group with 43 positives, which makes an average sporozoite rate of 1.1%. If only gland dissections had been performed, this rate would probably have been somewhat higher. Since — as will be discussed in following chapters — other malariometric indices are so much alike as between parts of Africa and New Guinea, a shorter average duration of life of anophelines of the *punctulatus* group may be held responsible for the relatively low sporozoite rates found in New Guinea, compared with those in *A. gambiae* in Africa. When climatological conditions become adverse, the average duration of life will be shortened even more, resulting in still lower sporozoite rates. This has indeed been put forward as the most probable

T

INFECTIONS IN AUSTRALASI

Species	Investigators	Locality	Num dissec
A. punctulatus	Toffaleti & King	Hollandia, New Guinea	
	Aberdeen	Milne Bay, New Guinea	
	Horsfall & Porter (1947)	Oro Bay, New Guinea	4
	Metselaar	Dojo, Sentani Lake, New Guinea	
	Metselaar	Nimboran Valley, New Guinea	21
	Metselaar	Nimboran Valley, New Guinea	2
	Metselaar	Biak, New Guinea	
A. farauti	Mackerras & Aberdeen (1946)	Wewak, New Guinea	2
	O'Sullivan	Wewak, New Guinea	1
	Aberdeen	Wewak, New Guinea	10
	Atherton & Lemerle	Lalapipi, New Guinea	5
	Roberts & O'Sullivan (1948)	Lalapipi, New Guinea	17
	Horsfall & Porter (1947)	Oro Bay, New Guinea	1
	Heydon	Cairns, Australia	15
	Toffaleti & King	Hollandia, New Guinea	
	Metselaar	Dojo, Sentani Lake, New Guinea	2
	Metselaar	Nimboran Valley, New Guinea	1
	Metselaar	Nimboran Valley, New Guinea	1
	Metselaar	Merauke, New Guinea	
	Voors	Baliem Valley, New Guinea	
A. koliensis	Toffaleti & King	Hollandia, New Guinea	1
	Metselaar	Dojo, Sentani Lake, New Guinea	3
	Metselaar	Nimboran Valley, New Guinea	2
	Metselaar	Nimboran Valley, New Guinea	2
A. punctulatus group	Heydon (1923)	Raboul, New Britain	1
	Heydon (1923)	Raboul, New Britain	1
	Bang & Hairston (1947)	Ramu Valley, New Guinea	2
	Bang & Hairston (1947)	Ramu Valley, New Guinea	6
A. subpictus	Roberts & O'Sullivan	Lalapipi, New Guinea	2
	Metselaar	Biak, New Guinea	
A. karwari	Toffaleti & King	Hollandia, New Guinea	1
	Metselaar	Dojo, Sentani Lake, New Guinea	1
A. amictus hilli	Roberts	Cairns, Australia	
	Metselaar	Merauke, New Guinea	
A. bancrofti bancrofti	Heydon	Cairns, Australia	
	Kok & Metselaar	Merauke, New Guinea	9

V

OPHELINES CAUGHT IN NATURE

Per cent. sporozoites	Remarks
0	In troop encampments
8.0 ±3.5	In hyperendemic native village
0.7 ±0.4	Mosquitoes were kept for 6 days before dissection, 1943, 1944
0	Stable holo-endemic native village. Thoracic juice slides, 1953
1.1 ±0.05	Stable holo-endemic native villages. Thoracic juice slides, 1954
1.4 ±0.7	Stable holo-endemic native villages. Gland dissections, 1955.
	Stable native village. Thoracic juice slides, 1954
2.0 ±1.0	In hyperendemic native village during war
0.6 ±0.6	In troop encampments, early in control period (June)
0	In troop encampments, control established, July, Aug., September
0	In hyperendemic native village during dry season in southern New Guinea; unfavourable survival conditions
0.06 ± 0.06	ditto
0	1943, 1944
0.65 ± 0.06	In civilian epidemic, 1942
0	In troop encampments
0.4 ±0.4	Stable holo-endemic native village. Thoracic juice slides, 1953
1.2 ±0.8	Stable holo-endemic native villages. Thoracic juice slides, 1954
2.4 ±1.4	Stable holo-endemic native villages. Gland dissections, 1955
0	In transmission-season in southern New Guinea. Thoracic juice slides, 1955
0	At 1600-1700 metres altitude. Probably no transmission
1.4 ±1.0	In troop encampments
1.1 ±0.6	Stable holo-endemic native village. Thoracic juice slides, 1953
0.5 ±0.5	Stable holo-endemic native villages. Thoracic juice slides, 1954
1.1 ±0.6	Stable holo-endemic native villages. Gland dissections, 1955
6.4 ±2.2	In native houses. Mosquitoes were kept a few days before dissection
0	In white quarters
1.7 ±0.8	Epidemic conditions among troops. Attack rate 2440-4000 p. 1000 men p. year
0.01	Troops under protection of prophylactic drugs. Attack rate 200 p. 1000 m. p. year
0	In hyperendemic native village during dry season in southern New Guinea; unfavourable survival conditions
0	Stable native village. Thoracic juice slides, 1954
0	In troop encampments
3.1	Stable, holo-endemic native village. Thoracic juice slides, 1953
1.3	In civilian epidemic due to A. farauti, 1942
0	In transmission-season in southern New Guinea, 1955
0	
0.2	In transmission-season in southern New Guinea, 1955. Collected from walls and mosquito nets in native quarters

explanation for the extremely low sporozoite rates found at Lalapipi in Australian New Guinea during the dry season (ROBERTS & O'SULLIVAN, op. cit.).

A different explanation probably holds good for VOORS's negative findings in the Baliem Valley, recorded in Table V. Besides the mosquito collections, he also took 653 blood samples, six of which were positive (three *P. vivax,* all with gametocytes, three *P. malariae,* one with gametocytes). The spleens of the parasite-carriers however were not palpable, and there were no appreciable symptoms of sickness. The possibility must therefore be taken into consideration that the infections were old, and caught during a sojourn at lower altitudes, the low temperatures prevailing in the valley being an impediment to the completion of the extrinsic cycle of the parasite, and thus to transmission.

In the laboratory *A. punctulatus* and *A. farauti* proved to be highly susceptible to experimental infections of *P. falciparum* from New Guinea and *P. vivax* from New Guinea and the Solomons. Differences in susceptibility could not be detected (MACKERRAS & ROBERTS, op. cit.). Our own field observations, which concern all three main species of the *punctulatus* group, give no indication as to differences in efficiency as between the above species, as vectors of malaria in nature. At first this may seem somewhat surprising, in view of the differences in biting habits, it being found — para. b — that *A. farauti* is rather indiscriminate in its biting habits and feeds on the nearest available host. However, the nearest available host will often be man, horses and cattle being practically unknown in the greater part of Netherlands New Guinea, while in many villages dogs, pigs, and fowl are rather scarce. The few goats that may be found are not attractive to *punctulatus* anophelines.

i. *Duration extrinsic cycle and gonotrophic cycle*

MACKERRAS & ERCOLE (1948 a and b) in the laboratory at Cairns, observed the duration of the extrinsic cycle of New Guinea strains of *P. falciparum. P. vivax* and *P. malariae* in *A. punctulatus.* Under temperature conditions comparable to those prevailing in the coastal areas of New Guinea, the development of *P. vivax* took slightly over 9 days, and of *P. falciparum* 11 days. At lower temperatures *P. malariae* needed 26 days and more. DE BUCK (1935) observed completion of the extrinsic cycle of *P. malariae* in *A. maculipennis atroparvus* in 15 days at a temperature of 27° C and a relative humidity of 90%; IYENGAR (1932) in 10, 14 and 19 days in *A. stephensi;* KLIGLER & MER (1937) in more than 22 days at a temperature of 27° C in *A. elutus.*

In the laboratory at Cairns (MACKERRAS & ERCOLE, op. cit.) development of the first batch of eggs took 72 hours after the first blood-meal; subsequent batches did not need more than 48 hours. As a rule one blood-meal was taken for the maturation of one batch. These facts correspond to what is usually found in mosquitoes in tropical climates.

j. *Survival rate*

The interrelationship between sporozoite rates, longevity, anthropophily, duration of extrinsic and gonotrophic cycles, and the infectivity to the mosquito of the parasite reservoir in man (gametocyte rate) has long been recognized. Recently, MACDONALD (1952a) has expressed this interrelationship in a mathematical formula reading as follows:

$$s = \frac{p^n \, ax}{ax\text{-}\log_e p}$$

in which

a = the average number of blood-meals *on man*, taken by a mosquito in a day;
p = the probability that a mosquito will survive through one day; (p is a fraction such as 0.8 and the converse of the probability of dying in one day, which would in this case be 0.2. In normal practice the latter is put as a percentage, and conforms to a daily mortality of 20%);
n = the time in days taken for the completion of the extrinsic cycle;
x = the proportion of bites on man which are infective to the mosquito;
s = the proportion of mosquitoes with sporozoites in their salivary glands;
e = the base of natural logarithms 2.71828.

Under the stable epidemiological conditions of malaria in highly endemic tropical regions, a, x, and n will usually show little variation. The greater will be the influence of variations of p on s, which influence is still more stressed because p is raised to the n-th power.

In the Nimboran Valley the average gametocyte-carrier rate of several surveys is 20%. When we take into account that not every carrier is infective to mosquitoes, and that children were better represented in the surveys than adults, an infective gametocyte reservoir of 10% of the population seems a reasonable estimate. The gonotrophic cycle for all three anopheline species under consideration may be estimated to last two days and let ten days be the duration of the extrinsic cycle. Table I shows an anthropophilic index of *A. punctulatus* of 85%, of *A. farauti* (somewhat arbitrarily) of 60%, and of *A. koliensis* also of 60%. Taking into account the various sporozoite rates found (Table V) and the differences in dissection technique, this rate can be calculated for *A. punctulatus* at 1.4%, for *A. farauti* at 1.5%, and for *A. koliensis* at 1.1%. Substituting these figures in MACDONALD's formula we find:

for *A. punctulatus*: $a = 0.43$, $x = 0.1$, $n = 10$, $s = 0.014$ (from which a value evolves of $p = 0.79$, which means a daily mortality of 21%);
for *A. farauti*: $a = 0.3$, $x = 0.1$, $n = 10$, $s = 0.015$ (from which evolves $p = 0.81$, or a daily mortality of 19%);
for *A. koliensis*: $a = 0.3$, $x = 0.1$, $n = 10$, $s = 0.011$ (which results in $p = 0.79$, or a daily mortality of 21%).

For *A. gambiae*, MACDONALD (1952a) has worked out approximate values of p based on figures from Tanganyika given by WILSON (1936). He comes to probabilities of survival through one day, varying between 0.93 and 0.97 and corresponding to sporozoite rates between 2.9% and 24.0%. In these examples the gametocyte rates varied also, viz. between 4.9% and 11.8%.

These values of p have no claim to exactness; they merely represent their order of magnitude. This, however, neatly fits into what may be expected. A great deal of their value lies in the possibility of comparison. They further illustrate that a slightly higher probability of survival of the anophelines, say, through one day, may compensate for less avidity for human blood, which may be a complementary explanation of the fact that sporozoite rates found in *A. farauti* are not, as a rule, lower than those found in the other two main species of its group (Table V). On the other hand, this fact gives support to the explanation — i.e. adverse conditions of life in the dry season —, given for the low sporozoite rates found in *A. farauti* at Lalapipi (Table V).

To show the importance of differences and changes in longevity, MACDONALD (1952c) worked out a few examples by which it is demonstrated that, when under otherwise stable conditions of endemicity the daily mortality of anophelines increases, the probability of survival through a number of days, and the expectation of life, are lowered in far greater proportion. Because of the importance of this fact, in view of the possible results of residual insecticide spraying, his figures are quoted in Table VI.

TABLE VI*

Period, days	Probability of survival through the period when the daily mortality is:				
	10%	20%	30%	40%	50%
10	0.349	0.107	0.028	0.006	0.001
15	0.206	0.035	0.005	0.0005	under 0.0001
20	0.122	0.011	0.0008	under 0.0001	
	Expectation of life for the above mortalities, in days				
	9.49	4.48	2.80	1.96	1.44

* From MACDONALD (1952 c) Table I

k. *Infective bites indoors and out of doors*

In 1948 SWELLENGREBEL estimated that in the *A. punctulatus* group outdoor transmission is three times as important as indoor infection, and that, as a consequence, residual spraying could not be expected to reduce malaria below two-thirds of its original incidence. In the light of newer

findings, and for the areas of New Guinea where the population lives fairly steadily in their villages, this view may at present seem too gloomy. The estimate that only one quarter of transmission occurs indoors should, in these villages, probably approximate to reality, if mosquitoes should indeed have the choice between indoor and outdoor feeding on man. However, this will rarely be the case, for by far the greater part, if not the whole, of the population in the village is usually indoors at night. Only in the early hours of the evening may part of the people sit out of doors. After 9 or 10 p.m. therefore mosquitoes are, as a rule, forced to go inside for their blood-meal. Moreover, the early hours of the night are probably of less importance with respect to transmission than the period after midnight. This, at least, may be concluded from the following observations.

In 1954 a total of six mosquito collections was organized in the Nimboran Valley, well divided over the year. Each collection lasted for a period of from five to twelve days. In the evenings we collected on human baits, by day from the inner walls of human dwellings. Thoracic juice slides were made for estimating the sporozoite rate. The results, which are shown combined in Table V, are given in detail in the following table.

1954	A. punctulatus		A. farauti		A. koliensis		A. karwari		Total		Per cent. positive
	No.	pos.	No.	pos.	No.	pos.	No.	pos.	No.	pos.	
Indoors by day from walls	1743	24	99	1	151	1	11	0	2004	26	1.3
On human baits *in evening hours* out of doors	414	0	73	1	65	0	2	0	554	1	0.2

The difference between the percentages of the two series is 3½ times the standard error of difference, and therefore significant. The following explanation may serve for it.

MUIRHEAD THOMSON (1951) observed for *A. minimus* and *A. gambiae* that after oviposition the female mosquito can return for a blood-meal the same night. It is not unlikely that this applies to other anophelines as well. Therefore a batch of mosquitoes caught during the second half of the night probably comprises a larger proportion of older mosquitoes, than a batch collected early in the evening. VAN THIEL & METSELAAR (op. cit.) proved that a significantly bigger proportion of anophelines of the *punctulatus* group, which entered an experimental hut after midnight, stayed there after dawn than of anophelines which entered before midnight. This could point to the possibility that, when anophelines of a relatively exophilic species are collected by day from inner walls, more older and

sporozoite-positive mosquitoes will be found in this sample, than in one collected on human baits in the early evening. This might explain the differences observed.

This assumption finds some support in observations made in 1955, when a number of "all-night" catches were organized in the same area. Reference has already been made to this kind of collections when discussing the prevalence of anophelines throughout the night. Each night two boys were on duty before and two others after midnight. They imitated the local people, which meant that at about 8 or 9 p.m. they usually had to go inside native's houses. The greater part of the anophelines collected by them are therefore mosquitoes collected on their own legs *indoors*. Gland dissections were made on mosquitoes collected in this way during a limited number of nights. This was also done on mosquitoes collected during that period on inner walls by day.

The results are shown in the next table.

1955	A. punctulatus		A. farauti		A. koliensis		Total		Per cent. positive
	No.	pos.	No.	pos.	No.	pos.	No.	pos.	
Indoors by day from walls	90	1	32	1	57	0	179	2	1.1
On human baits, *all night*, (imitating local people)	196	3	93	2	208	3	497	8	1.6

This time mosquitoes coming for their blood-meal in the second half of the night are included in the catches on human baits. The result is a much higher sporozoite rate than that of the 1954 series, which consisted of anophelines collected on human baits, out of doors, and in the early evening hours only. The difference is 2.3 times the standard error of difference. Significance may therefore be attached to it. Even when, in view of the different dissection techniques, we make allowance for the sporozoite rate derived from the evening catches, and substitute 0.4 for 0.2, the probability that the difference is due to chance is still less than 5%.

In the 1955 series the "all-night" catches show a higher sporozoite rate than the "day-time" indoor catches. This difference, however, is not significant and may be due to chance.

Where, in New Guinea, people live fairly steadily in their villages, it may therefore be assumed, on the ground of the foregoing observations and considerations, that infection for a good deal takes place indoors, or at any rate to a greater extent than was previously thought. Because the extrinsic parasite cycle lasts approximately 5 times as long as the gono-

trophic cycle, this implies that the greater part of the anopheline population in and near villages will enter human dwellings at some time or another during this extrinsic cycle. When these are sprayed with residual insecticides, this will result in a considerable shortening of the average expectation of life of this population. In the light of the figures produced by MACDONALD (Table VI) it will be clear that this must have an enhanced influence on the sporozoite rate, and thus on malaria transmission. On theoretical grounds it may therefore be expected that in New Guinea, under the conditions described, residual insecticide spraying will reduce malaria considerably below the two-thirds of its original incidence which was held maximally possible by SWELLENGREBEL.

Unfortunately, transmission need not occur exclusively in the villages, but may also take place in the vegetable- and sago gardens when people are in the habit of spending the night there now and then. In this respect customs in New Guinea vary greatly between permanent settlement and almost complete nomadism. And because the degree of exophily of the human population determines the degree of exophagy of the anophelines, these customs are surely of decisive importance for the degree of success of residual spraying.

B. OTHER ANOPHELINES

Some other anopheline mosquitoes prevailing in Netherlands New Guinea still need brief discussion.

1. *A. clowi* Rozeboom & Knight, the fourth member of the *Anopheles punctulatus* group, has so far not been encountered in sufficient numbers to be of epidemiological importance.

2. *A. karwari* James is classed among the oriental anophelines. Its most eastern location in Asia is Celebes. East of Celebes it has been found in only one place in the Australasian region, namely near Hollandia in Netherlands New Guinea. It was observed there for the first time by DE ROOK (1938).

Generally speaking, the larvae show preference for slow-running water e.g. small streams, seepage water, rice-field irrigation canals, etc. However, they have also been found in such stagnant water as ponds (ESSED, 1925) and in hoof-prints (DE ROOK, 1950). The breeding places are exposed to sun or lightly shaded. Nothing is known of the diurnal outdoor resting places of the adult mosquitoes, but they are often found indoors, both in human dwellings and in cattle sheds (DOORENBOS, 1931; GATER, 1935; TOFFALETI & KING, 1946; NAIR, 1947; MCARTHUR, 1947). They attack both man and animal, though the latter seem to be preferred. RAMSEY et al. (1936) found an anthropophilic index of 16.4% by means of the precipitin test, MCARTHUR (1947) of 17% by means of bait traps. Summarizing records by SWELLENGREBEL et al. (1919), SCHÜFFNER & HYLKEMA (1921), DOORENBOS (1931), MANALANG (1928), GATER (1935), LAMPREL (1936),

McARTHUR (1947) and KING & HOOGSTRAAL (1946), I find that only two gland infections have been reported from more than 21,000 dissections performed in many parts of *A. karwari's* distribution area. However, these two sporozoite-positive *A. karwari,* recorded by GATER, were, according to HODGKIN (1950), kept in captivity for at least seven days before being dissected. This makes this observation worthless.

It may therefore be asserted that until recently *A. karwari* has never been found with sporozoites in nature, and that in the Asiatic part of its distribution area it may be regarded as a harmless species.

Near Hollandia in Netherlands New Guinea, 995 out of a total of 10,332 anophelines collected in 1953 and the first quarter of 1954, were determined as being *A. karwari* (9.5%). All were collected on human baits or inside human dwellings. This shows that it is a common species near Hollandia, and that it readily attacks man. This was confirmed by the experiments of VAN THIEL & METSELAAR (op. cit.) which, moreover, showed that in its feeding habits *A. karwari* behaves much like the *punctulatus* anophelines.

In a series of 128 dissections from Dojo (Sentani Lake), four (3.1%) contained sporozoites (Table V), which makes it clear that *A. karwari* is an important vector of malaria in the Hollandia area. This is the first record of natural infections with sporozoites in *A. karwari.*

One reason why experiences near Hollandia may differ from those in the Asiatic part of its distribution area is probably that there are no water buffaloes near Hollandia, and that cattel is scarce. There is therefore no deviation of the vectors to these animals. The figures of Table II show that, with regard to its biting activity, *A. karwari* has a marked preference for the second half of the night. Of the catches before midnight 3.2% were *A. karwari,* against 37.8% of those after midnight. On other occasions the same phenomenon could be observed (METSELAAR, 1955).

3. Of *A. subpictus* Grassi, the position in New Guinea as a vector of malaria is not yet clear. Besides the type-form *A. subpictus subpictus,* two varieties have been described: *A. subpictus indefinitus* Ludlow and *A. subpictus malayensis* Hacker. Like *A. karwari, A. subpictus* belongs to the oriental anophelines, and is extending its distribution area in an eastern direction. It was known to occur in restricted areas along the south coast of Australian New Guinea, and has recently been recorded from Guam by REEVES & RUDNICK (1951) and from Biak, an island in the Geelvink Bay in Netherlands New Guinea, by DE ROOK (1954). To which of the three varieties the New Guinea *subpictus* belongs has never been defined. Of those from Australian New Guinea, KING (1949) states that they differ distinctly from the type-form of India. Of those from Biak nothing is known.

On Biak, *A. subpictus* larvae could be collected only from artificial brackish water ponds along the coast. The adults were a real nuisance for the population of the nearby villages. After the ponds had been opened

to the sea, neither larvae nor adults could be collected any longer. Nevertheless, when after six months the openings were closed again by tidal action, *subpictus* reappeared, to disappear again below detectable numbers when the ditches were restored.

At times of abundance adults of *A. subpictus* could easily be collected from the inner walls of houses. This is also reported by VAN THIEL & WINOTO (1951) from Java, and by BAYLEY (quoted by MACKERRAS, 1947) from Australian New Guinea. In Asia, cattle sheds seem to be its favoured resting places. This is in accordance with records of precipitin tests which also show preference for animal blood: ALFRIDI et al. (1939) 0% human blood in 1824 *A. subpictus;* RUSSELL & JACOB (1939) 3.1% in 520; WALCH & SARDJITO (1928) 13% in 48. Only in Indonesia was *A. subpictus* found with sporozoites (VAN HELL, 1952). Numerous dissections on the Asian continent and 263 in Australian New Guinea (Table V) were all negative. We performed only 80 dissections and could not detect any sporozoites either. At the same time, one sporozoite-positive *A. punctulatus* was found in 17 females of that species.

It seems not impossible that in Biak, where hyperendemic conditions are kept up by anophelines of the *punctulatus* group, *A. subpictus* has played a minor part in transmission in a small area of the island.

4. *A. bancrofti* Giles is another anopheline species which is of minor importance only locally in New Guinea. Its distribution area is mainly northern Australia and southern New Guinea. It has also been found in northern New Guinea. Near Hollandia the species could be found regularly in small numbers.

In southern New Guinea it eagerly attacks man and can easily be collected from inner walls and mosquito nets. It was suspected as a vector of malaria in Tanah Merah by DE ROOK (1929), but no gland dissections were performed. HEYDON (quoted by MACKERRAS, 1947) did not find any sporozoites in 74 specimens collected at Cairns, Australia (Table V). In Merauke, where *A. farauti* may be regarded as the main vector, dissections were performed on 982 females during the transmission season of 1955, two of which contained sporozoites (Table V, KOK & METSELAAR). This is the first record of natural infections with sporozoites in *A. bancrofti.*

5. In southern New Guinea *A. amictus hilli* Woodhill & Lee may be another vector species. It occurs also in northern Australia, where ROBERTS (quoted by MACKERRAS, 1947) found one female infected with sporozoites in 79 dissected ones (Table V). This was during an epidemic due to *A. farauti.* So far it has not yet been found with sporozoites in southern New Guinea, 58 dissections being negative (Table V).

6. A few other species occurring in New Guinea have been experimentally infected, namely *A. amictus* Edwards, *A. annulipes* Walker, *A. stigmaticus* Skuse and *A. longirostris* Brug (ROBERTS, 1943; MACKERRAS & ROBERTS, 1947). So far there are no indications that these species are of epidemio-

logical importance. In the Trobriand Islands, however, *A. longirostris* must be watched closely, since it is greatly increasing in numbers there (BLACK, personal communication).

The position of *A. meraukensis* Venhuis as a possible vector of malaria needs investigation.

It may thus be concluded that *A. punctulatus, A. farauti* and *A. koliensis* are the main vector species of malaria in New Guinea.

CHAPTER II

THE EXPERIMENT WITH WINDOW-TRAPPED HOUSES

Full descriptions of the experimental houses which were used in this experiment, of the observations regarding the feeding- and biting habits of the local anophelines, and of the results observed during the first six weeks after spraying of two of the three houses with insecticides, were given by VAN THIEL & METSELAAR (op. cit.).

Briefly summerized, this part of the pilot-project was performed in three experimental huts, of the same construction and material as the normal native houses, and fitted with outlet traps in the windows and movable valves in the eaves. After observations on the bionomics of the anophelines had been completed, the inner walls of house I were sprayed with a suspension of 5% DDT wettable powder, i.e. 2 grams DDT per square metre, of house II with a 1.25% emulsion of dieldrin (Dieldrex 15), i.e. 500 mg dieldrin per square metre, while house III was left unsprayed and served as control. The actual amounts of insecticides present on the walls were not chemically estimated. There was a human bait in each of the three houses from 7 p.m. to 6 a.m. during all tests. At first the eaves of all three houses were constantly open, and an oil lamp burned inside the houses. Later on the oil lamp was extinguished in all three houses at midnight, and the eaves closed in control house III at the same time, as this was found to be instrumental in bringing more anophelines into the traps. The floors were covered with white sheets, from which the dead mosquitoes were collected early in the morning after each test. Rags soaked in vaseline and wrapped around the poles of the houses prevented ants from entering.

The traps remained fixed in the windows from 7 p.m. to 6 a.m., after which they were taken to the laboratory, where the dead mosquitoes were collected; the living specimens were left in the same cages and placed in a room safe from ants and draughts. Wet towels covered the cages and provided a humid atmosphere inside. Care was taken that the traps were not contaminated with insecticides. Dead mosquitoes were again collected from the cages 12, 24, 36, and 48 hours after these had been placed in the laboratory, and for the first 6-week period after spraying the survival rate was calculated accordingly. Later on the number of anophelines diminished considerably, due to an abnormally low rainfall, and the survival rate was calculated only after 24 and 48 hours.

By the time thirty weeks had elapsed, mosquitoes were so scarce that observations had to be interrupted. Later on all the houses for miles around

TABLE VII

RESULTS OBTAINED IN WINDOW-TRAP HUTS AT HOLLANDIA.

Period after spraying	I 1 st. — 6 th. week						II 7 th. — 12 th. week						III 13 th. — 18 th. week						IV 19 th. — 24 th. week						V 25 th. — 30 th. week					
Number of tests	15						4						7						7						7					
House sprayed with:	D.D.T.		Dieldrin		Un-sprayed control		D.D.T.		Dieldrin		Un-sprayed control		D.D.T.		Dieldrin		Un-sprayed control		D.D.T.		Dieldrin		Un-sprayed control		D.D.T.		Dieldrin		Un-sprayed control	
Anophelines:	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Dead on floor at dawn:	332	66	111	61			84	65	9	25			12	16	6	7			13	35	5	10			6	40	5	23		
Dead in traps at dawn:	68	13.5	63	35			18	14	25	69			20	26	37	42			5	13.5	6	12			2	13	5	23		
Dead in traps after 24 h.:	68	13.5	7	4	14	10	12	9	1	3	4	11	23	29	31	35	0	0	5	13.5	7	14	10	21	1	7	3	13	5	14
Survivors after 24 hours:	34	7	0	0	127	90	15	12	1	3	33	89	22	29	14	16	32	100	14	38	31	64	37	79	6	40	9	41	30	86
Dead in traps after 48 h.:	10	2	—	—	38	26	7	6	1	3	9	24	9	12	4	5	5	16	8	22	5	11	10	21	3	20	3	13	2	6
Survivors after 48 hours:	24	5	0	0	89	64	8	6	0	0	24	65	13	17	10	11	27	84	6	16	26	53	27	58	3	20	6	28	28	80
TOTAL:	502		181		141		129		36		37		77		88		32		37		49		47		15		22		35	
Corrected mortality rate		89		100				87		100				69		78				62		47				67		55		

were sprayed, with so much contamination with DDT everywhere, that even the mosquitoes in the window-traps of the unsprayed control house died and further observations became worthless.

For convenient comparison with the figures already published, the complete period of thirty weeks of observations has been divided into five periods of six weeks (period I—V). Because of the small numbers of anophelines in period IV and V, the figures could not be calculated for each anopheline species separately. The combined results for all collected anophelines are tabulated in Table VII.

In the control house, no dead anophelines were collected from the floor, and only once were a number of *A. karwari* found dead in a trap when the latter, for special reasons, was removed from the control house later in the morning, and had been exposed to the sun. Natural mortality as such cannot be expected in mosquitoes fit enough to enter a test-house for a blood-meal and not exposed to any risk of death apart from that caused by spiders or lizards. The death of mosquitoes found dead in the morning on the floor and in the traps of the sprayed houses ("morning mortality") can therefore be regarded as completely due to the insecticides. This is not the fact with the "delayed mortality", i.e. of mosquitoes found in the traps kept for 48 hours in the laboratory. Allowance has here to be made for any mortality occurring among mosquitoes in the traps of the control house. This has been done by using ABBOTT's formula (1925). Only the mortality found in the dieldrin traps during period IV is uncorrected, because the mortality among the controls was higher. The sum of the morning mortality and the corrected delayed mortality is the corrected mortality. The corrected mortality rate can be found in Table VII.

A. *The DDT experimental house I*

In Table VIII A, our results are compared with records published by various other authors. For this table, experiments were selected in which wettable powder was used in a dosage comparable to our own. Moreover, an experiment that failed because of the large crystal size in the formulation used, was omitted from the table (MUIRHEAD THOMSON, 1950; HADAWAY & BARLOW, 1951). It will be seen that our results are among the best that have been recorded.

It has been observed that DDT exerts a distinctly irritating effect on mosquitoes, due to which they do not rest long on treated surfaces. Also that mosquitoes, excited by the poison, move preferentially towards the light (METCALF et al., 1945; KENNEDY, 1947). These properties of DDT explain why several authors could collect more anophelines — dead or alive — from the window-traps than from the floor. When compared with gammexane, the percentage found in the window-traps of DDT huts was usually higher than in traps of BHC huts (BERTRAM, 1950; GILROY, 1951; WHARTON, 1951 a and b; DOWNS & BORDAS, 1951; DAVIDSON, 1953). According to DAVIDSON (1953) a large proportion which had contact with

TABLE VIII
COMPARISON OF RESULTS OBTAINED IN WINDOW-TRAP HUTS.

	Authors	Mosquitoes	Material of huts	Dosage: DDT g/m²	*) Corrected mortality rate (%) Months after spraying									Remarks
					1	2	3	4	5	6	7	8	9	
A.	Wilkinson (1951)	A. gambiae. A. funestus.	Mud: thatched roofs	1.6	90	70	57							Morning mortality rate only
	Van Tiel (1952)	A. gambiae. A. funestus.	Wood	1.9	100	100	100	100	100	100				All were found dead in morning Few mosquitoes (72 in 6 months)
	Davidson (1953)	A. gambiae. A. funestus.	Gravel and mud, thatched roofs	2.5	54	65	60	58	64	47	50	61	56	Delayed mortality after 48 hours included.
	Bertram (1950)	A. minimus. A. vagus. Culicines.	Mud plaster, thatched roofs	2.4	75									
	Gilroy (1951)	A. minimus and other anophelines	Mud and dung, thatched roofs	2.0	51									Delayed mortality after 24 hours included. After first month mortality low. Better results with smaller dose of D.D.T.!
	Wharton (1951 a)	A. maculatus	Wood, lined with packing paper, thatched roofs	2.2	83	81	83	87						Delayed mortality after 24 hours included.
	Wharton (1951 b)	A. maculatus	Ditto	2.2			65	70	69	43	36			Delayed mortality after 48 hours included. Sprayed beforehand to coincide in 3rd-7th month with maximum mosquito prevalence.
	Downs & Bordas (1951)	A. pseudopunctipennis	Adobe, thatched roofs	2.2									77	Delayed mortality after 48 hours included.
	Van Thiel & Metselaar	A. punctulatus group. A. karwari	Ribs of sago palm, thatched roofs	2.0	89		87	69		62	67			Delayed mortality after 48 hours included.
B.				Dieldrin mg/m²										
	Davidson (quoted by Macdonald & Davidson, 1953)	A. gambiae. A. funestus	Gravel and mud, thatched roofs	600 (wett. powder)	100	100	100	90	91	87	81	88	95	Delayed mortality after 48 hours included. In 12th and 23rd month still a corr. mort. rate of 91% and 49% respectively.
	Van Thiel & Metselaar	A. punctulatus group. A. karwari	Ribs of sago palm, thatched roofs	500 (emulsion)	100		100	78		47	55			Delayed mortality after 48 hours included.

*) Derived from MACDONALD & DAVIDSON (1953)

DDT, were irritated so soon that they flew towards the light before they had taken a lethal dose, while this irritant action was almost absent in dieldrin.

This irritant action of DDT was not so evident in our experiments. Throughout the period of observation, a large proportion of the dead mosquitoes could be collected from the floor-sheets of the DDT house, and always a higher percentage than from inside the dieldrin house. On the other hand, of the anophelines that reached the window-traps the morning mortality was usually higher among the dieldrin mosquitoes, which indicates that these had picked up a relatively larger dose of the insecticide. These facts could be explained by assuming that a number of excited anophelines had escaped through the eaves of the DDT house, in which case the total corrected mortality by DDT must be lower than calculated. In view of the high delayed mortality in the traps it need not be feared that the anophelines were irritated so soon that they took off before they had taken a lethal dose. In the control house, escape most probably occurred through the eaves, because after we had decided to close the eaves of this house at midnight, more anophelines were found in the window-traps.

Since the eaves of the control house were closed at midnight, comparison between the numbers collected in this hut and in the sprayed houses is impossible. Conclusions with regard to a possible repellent action operating over a distance, as suggested by DOWNS & BORDAS (op. cit.), and which would prevent mosquitoes from entering, are therefore impossible.

In the publication by VAN THIEL & METSELAAR it is stated that on mornings after each test both gorged and ungorged anophelines were found dead on the floor and in the window-traps of the sprayed houses, and that therefore spraying of the walls with insecticides does not protect man against being bitten.

TABLE IXA
ANALYSIS OF THE ANOPHELINES COLLECTED IN THE DDT-SPRAYED HOUSE I.

Number of:	A. punctulatus		A. farauti		A. koliensis		A. karwari		A. longirostris	
	+	—	+	—	+	—	+	—	+	—
Dead on floor:	69	13	71	32	146	58	63	52	1	2
Dead in cages at dawn:	10	8	16	17	28	27	2	2	1	0
Alive in cages at dawn:	17		78		97		10		0	
Total gorged and ungorged:	79	21	87	49	174	85	65	54	2	2
Percentage:	79	21	64	36	67	33	55	45	50	50

+: gorged
—: ungorged

TABLE IX B
ANALYSIS OF THE ANOPHELINES COLLECTED IN THE DIELDRIN-SPRAYED HOUSE II.

Number of:	A. punctulatus		A. farauti		A. koliensis		A. karwari		A. longirostris	
	+	—	+	—	+	—	+	—	+	—
Dead on floor:	35	9	23	11	65	10	12	4	0	0
Dead in cages at dawn:	13	5	40	17	49	20	2	1	0	0
Alive in cages at dawn:	14		56		28		4		0	
Total gorged and ungorged:	48	14	63	28	114	30	14	5	0	0
Percentage:	77	23	69	31	79	21	74	26	—	—

+: gorged
—: ungorged

The analysis of the anophelines collected during the complete period of observation in the DDT house may be found in Table IX A. It was not recorded whether the anophelines which survived after dawn were gorged or not (this being indicated in the table by placing these specimens between the numbers of gorged and ungorged anophelines), as this could not always be ascertained when the mosquitoes had been kept in captivity for 24 hours or more. It is therefore not possible to calculate whether the mortality was higher among gorged mosquitoes than among ungorged ones, as was found by TRAPIDO (1946).

It is evident that DDT needs to be re-sprayed every six months.

B. *The dieldrin experimental house II*

In Table VIII B our results in the dieldrin house are compared with those found by DAVIDSON (quoted by MACDONALD & DAVIDSON, 1953). DAVIDSON sprayed his hut with wettable powder; our hut was sprayed with an emulsion.

When comparing the results obtained in our dieldrin house with those of our DDT house (Table VII), it is seen that, at first, a higher morning mortality was caused by dieldrin. Moreover, the total corrected mortality rate by dieldrin is 100% in the periods I and II, while in the DDT house a few survivors were found. This higher initial insecticidal potency of dieldrin is in accordance with laboratory observations (BUSHVINE & NASH, 1953; WHARTON, 1955), and is due to higher toxicity and lesser irritant effect of the latter insecticide. But apart from the better initial kill, a longer persistence of the insecticidal power of dieldrin has also been observed, both in the laboratory (BUSHVINE & NASH, op. cit.) and in the field (DAVIDSON, quoted by MACDONALD & DAVIDSON, op cit.). This longer persistence was not evident in our experiment. In the periods IV and V mortality by DDT was higher, though not significantly so, than by dieldrin. Chapter III describes how a comparable phenomenon was seen in the

field experiment in the Nimboran, five months after spraying, and further discusses the subject. It may be remarked here that the formulation used is probably responsible for the disappointing results, and that repetition of this part of the experiment may be necessary.

The number of mosquitoes that entered the dieldrin house during period I is low compared to that of the DDT house. There was a noticeable smell in the hut shortly after spraying, and the possibility of a repellent action, operating over a distance (DOWNS & BORDAS, op. cit.) is not, therefore, precluded.

The analysis of the anophelines collected in the dieldrin house is given in Table IX B. In common with DDT, dieldrin did not prevent mosquitoes from biting.

With the aid of the results obtained in our experiment, those of DAVIDSON in his experimental hut sprayed with dieldrin, and the entomological data described in Chapter I, it is possible to attempt a prognosis of the probable results of the application of the insecticides under field conditions in New Guinea. This can best be done by means of the mathematical formula, recently developed by MACDONALD (1952b), but differing from that used in Chapter I. MACDONALD considers the equilibrium in malaria which "refers to the level at which the parasite rate or other index of the proportion of people affected, will stabilize itself at the end of a period of change. This equilibrium may be established at zero, that is by extinction of the disease, at some level between zero and 1.0 (0 and 100 per cent.), or at 1.0". When the proportion of the population receiving infective inocula in one day does not exceed the proportion of affected people who have received one infective inoculum only and who revert to the unaffected state in one day, this equilibrium may establish itself under certain conditions at the limit of zero. This is attained when:

$$m = \frac{-r \log_e p}{a^2 b p^n}$$

in which

m = the anopheline density in relation to man,
a = the average number of man bitten by one mosquito in one day,
b = the proportion of those anophelines with sporozoites in their glands which are actually infective,
p = the probability of a mosquito surviving through one whole day,
n = the time taken for the completion of the extrinsic cycle,
r = the proportions of affected people, who have received one inoculum only, who revert to the unaffected state in one day,
e = the base of natural logarithms, 2.71828.

MACDONALD (1950b) calculated the average duration of parasitaemia in an untreated case of *P. falciparum* infection at 200 days. No data are available which enable us to calculate this duration for *P. vivax*, but it

may be roughly estimated at 330 days (see Chapter III, para. D.a.1). Because *P. vivax* is most difficult to eliminate by residual insecticides, the figure 330 will be used for the calculation of r, which then becomes $\frac{1}{330} = 0.003$.

The average corrected mortality in the DDT house during the time of observations was 75%. The average daily mortality of anophelines of the *punctulatus* group may be put at 20% (Chapter I, para. A.j). If each anopheline should enter a DDT-sprayed house once in each gonotrophic cycle, the probability of survival through one day would be $\sqrt{0.80 \times 0.25} = 0.45$, which figure may be substituted for p.

The average a for the *punctulatus* group is approximately 0.35 (Chapter I, para. A.j).

The species of malaria parasites with the shortest extrinsic cycle is most difficult to control by residual insecticides. This species is *P. vivax*. The duration of its extrinsic cycle is nine days (MACKERRAS & ERCOLE, op. cit.), which figure will be substituted for n.

Recently, MACDONALD (1955) expressed doubt whether bites of anophelines with low sporozoite densities in the salivary glands are always infective. On epidemiological grounds he comes to the conclusion that they often are not. According to him, ineffective bites will often occur in highly endemic areas because, due to immunity, the number of gametocytes will seldom be abundant in parasite-carriers living in these areas, and low sporozoite densities in the mosquitoes will be the rule. That, under these circumstances ineffective bites may happen seems, indeed, not unlikely. The supposition finds support in laboratory experiments by BOYD (1940). Two widely separated values will therefore be substituted for b in the formula, viz. $b = 1.0$ (all bites of sporozoite carriers infective) and $b = 0.3$ (about one third of these bites infective).

If $b = 1.0$, m can be calculated at 26; with $b = 0.3$ m becomes 86. These figures mean that, if the number of anophelines in relation to one man, under the assumed circumstances, remains below 26, respectively below 86, malaria is under control. The latter values are termed the "critical density".

From Table IV it will be seen that in the Nimboran one man will on an average be bitten by about 35 anophelines per night, which, because $a = 0.35$, corresponds to a density of about 100 anophelines per man. Assuming that this figure represents the order of magnitude of value in more parts of New Guinea, and that the actual critical density lies between the two values calculated, complete control of malaria with DDT indoor-spraying in the whole island will be impossible. Only in areas of New Guinea where relatively low anopheline densities occur, eradication of the disease might be achieved. These conclusions will most probably be correct, even when one considers that the actual density of mosquitoes will be decreased by the insecticide, a factor which is not taken into account in MACDONALD'S formula.

Moreover, for the calculation of p it has been assumed that the anophelines bite indoors only. In Chapter I, however, it was argued that not all anophelines do so. Even in areas where the population lives steadily in the villages, some outdoor biting occurs shortly after sunset.

When, with the values for b, as used in the above calculations (viz. 1.0 and 0.3) allowance is made for outdoor biting and values for the critical density are calculated if anophelines should, on an average, enter a DDT sprayed-house once in 2½ nights, or respectively, once in 3 nights, the following figures evolve:

Contact of anoph. with DDT. Once in:	2 nights		2½ nights		3 nights	
Probability of survival through one day (p):	0.45		0.5		0.54	
Proportion of infective spor. pos. anoph. (b):	1.0	0.3	1.0	0.3	1.0	0.3
Critical density (m):	26	86	8	28	4	13
Corresponding number of bites per man per night:	9	30	3	10	1	5

It is clear that, when the proportion of infective bites of sporozoite-positive anophelines (b) is even lower than 0.3 the critical density of mosquitoes is higher.

The value of p, when mosquitoes enter a DDT-sprayed house, say, once in 2½ nights, is calculated as follows: once in 2½ nights is twice in 5 nights. For the 24 hours in which the mosquitoes enter the sprayed houses, the probability of survival is 0.25, for the others 0.80. The average p is therefore $\sqrt{0.80^3 \times 0.25^2} = 0.5$. The other values of p are calculated accordingly.

Unfortunately it is not known which of the values of b is nearest to reality, but the overwhelming importance of the social habits of the population, in areas where DDT is used as a residual insecticide, is nevertheless clearly illustrated by the figures of the table. Relatively slight increases in the rate of outdoor biting of anophelines have an enhanced effect on the possibilities of transmission, because they greatly diminish the critical density of mosquitoes below which complete control can be achieved. In areas of relatively low anopheline densities, and within the assumptions made, the difference between complete protection by indoor-spraying and practically complete failure is determined by almost no possibilities for mosquitoes to obtain a blood-meal out of doors, and the possibility of feeding in the open about once in six nights. In terms of human habits this means that, in those areas, complete protection will be possible only if the population would stay indoors practically from sunset to dawn; while intermediates between moderate protection and almost complete

failure will be found according as the habit of sitting outside in the evening is more widespread. The same conclusion holds good according as there are more unsprayed or poorly sprayed houses in an area, or where too much of the DDT is removed from the walls, because people have a habit of leaning against the sprayed surfaces.

Quite a different problem arises when people are in the habit of spending the night in the gardens now and then. Foci of transmission will then be maintained there, which are not influenced by DDT, and even in areas with low anopheline densities, eradication of the disease will not be achieved.

As already stated, our results in experimental house II, which was sprayed with dieldrin, cannot be applied as a standard for this insecticide. The figures obtained by DAVIDSON (Table VIII B) probably correspond better to its insecticidal potency and persistence. This author observed that an average kill of over 90% was maintained for at least one year by dieldrin. When, with the aid of this figure, similar calculations are made for dieldrin as were made for DDT, the following results are obtained:

Contact of anoph. with dieldrin. Once in:	2 nights		2½ nights		3 nights		4 nights	
Probability of survival through one day (p):	0.28		0.35		0.4		0.48	
Proportion of infective spor.-pos. anoph. (b):	1.0	0.3	1.0	0.3	1.0	0.3	1.0	0.3
Critical density (m):	1800	5900	330	1100	85	280	13	44
Corresp. number of bites per man per night:	630	2050	115	385	30	98	4	15

These figures make it clear that the possibilities of dieldrin in the control of malaria by indoor-spraying far exceed those of DDT. Even when anophelines are offered the chance of obtaining a blood-meal out of doors about once in three nights, good results seem to be possible by the use of dieldrin. It is therefore the insecticide of choice in areas of severe endemicity, the more so because the intervals between sprayings can be longer. In view of experiences in Africa this is not sure. In several regions of that continent, dieldrin has to be applied every six months (WHO, 1956a).

But also in areas where the houses are sprayed with dieldrin, the habit of spending the night in the gardens or on sago-marshes will detract from the results.

What has been remarked in Chapter I about the exactness of the figures calculated with the aid of a mathematical formula, is also true for the figures calculated above. Their intention is to illustrate their order of

magnitude only. Moreover, the degree in which a change in one factor, which has a bearing on malaria transmission, influences the others, is well illustrated. It is clearly shown that relatively minor differences in the social habits of the population, and minor differences in the mortality of the mosquitoes in relation to these habits, may decide whether control with indoor-spraying will be possible or not. Another advantage of these formulae is, that gaps in our knowledge of the epidemiology of malaria and other diseases became apparent, which will stimulate further research.

CHAPTER III

THE FIELD EXPERIMENT

A. The Experimental and Control Areas

a. *Geography and connections (see Map)*

The experimental area is situated south-west of Hollandia in the basin of Sentani Lake, which on its northern side is separated from the Pacific Ocean by the Cycloop Mountains (2360 metres) and on the other three sides surrounded by hills not higher than 550 metres. The elevation of the lake itself is about 70 metres above sea-level. Along the northern coast, between the lake and the Cycloop Mountains, are some plains, whose lower part is formed by extensive sago-marshes, while along the other sides many smaller marshes form an equal number of potential anopheline breeding places. For practical reasons, related to this experiment, the Sentani basin will be divided into the "Lake Area" which is the experimental area proper, and the "Surrounding Area".

The lake itself is about 30 km long and 10 km wide. It derives its water from the many brooks and rivers coming down from the hills and the mountains. In the south-east corner there is a narrow break in the ring of mountains and hills through which surplus water runs off. However, in periods of heavy rainfall the water-surface of the lake may rise by about one metre, flooding the surrounding marshes and favouring the breeding of numerous anophelines. This situation resembles that of the Santee reservoir in South Carolina, described by Atchley et al. (1955).

A road from Hollandia to the Tanah Merah Bay runs along the northern side of the lake, while a ferry crosses it from east to west, and connects with a point where a jeep road begins, enabling us to reach the "Control Area", situated about 25 km further west in the centre of the Nimboran Plain, which forms the western part of the Grimé Plain, a vast valley covered with many marshes.

A motor launch of the Public Health Service was at our disposal when we needed it for experimental work on the lake.

b. *Climate*

Rain is perennial in both areas, with, as a rule, maxima in the period January-March and minima in the period June-August. Table X shows, besides the averages for a number of successive observation years, the figures for 1953, 1954, 1955 and part of 1956. The difference between

TABLE X

RAINFALL IN THE LAKE AREA AND IN THE NIMBORAN CONTROL AREA

Senkani Meteorological Station

	Jan.	Febr.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Average of 8 years	192	263	264	199	108	85	67	129	111	121	188	167	1896
1953	66	265	126	210	241	55	78	187	187	113	203	133	1864
1954	202	204	430	194	64	29	55	27	92	182	149	182	1810
1955	202	295	330	209	160	99	23	33	53	77	156	203	1840
1956	186	178	191										

Genjem in Nimboran Valley

	Jan.	Febr.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Average of 17 years	357	263	336	289	168	127	148	142	134	173	199	260	2596
1953	209	378	325	211	216	133	138	234	192	337	301	253	2927
1954	265	422	444	240	154	158	63	99	75	152	195	188	2455
1955	295	318	658	203	202	147	8	99	58	121	342	254	2705
1956	203	168	228										

the averages of the totals for the two areas is six times the standard error of difference, and consequently significant. It is therefore obvious that the Nimboran has a higher rainfall than Sentani. Since 1959 the Sentani Meteorological Station has made records of temperature and relative humidity. The figures for 1964 are reproduced here; they do not differ substantially from those of the other years.

	Temperature in °C			Relative humidity (%)		
Local time	06.30	12.30	18.30	06.30	12.30	18.30
Year average	22.6	30.3	25.5	93	70	85

July had the lowest average morning temperature (21.9° C).
October the highest average midday temperature (32.3° C).
The absolute maximum and minimum were 34.3 C and 17.5° C respectively.
From the Nimboran no such records are available.

c. *Houses*

The native houses are built on poles with both the inner and outer walls of "gaba-gaba" or rows of ribs of the sago-palm (*Metroxylon* spec.) fixed vertically and tightly between the beams of the wooden frame; the roofs are of "atap" from the sago-palm leaves. Another species of palm (*Arenga* spec.) provides the floor planks. On an average the outer walls are 2 metres high. Corrugated iron is also used for the huts.

d. *Inhabitants*

The inhabitants of New Guinea are Papuans a Melanesian negroid race.
In the Sentani basin the native villages inhabited by some 3500 Papuans are mainly in the Lake Area on small islands or along the shore, with houses built over the water. In the Surrounding Area, there are five more native villages, situated along the western part of the road and with about 500 inhabitants. About 1500 settlers and Papuans live on the plains north of the lake. These numbers are rather small for a pilot project, but in sparsely populated New Guinea it will be difficult to find a more favourable concentration of population, and situated within easy reach by boat or car. Moreover, it would have been very difficult for our small staff to handle more people. The difficulties inherent in the statistical handling of small figures had therefore to be accepted.

Mosquito nets are seldom or carelessly used by the inhabitants of the area.

As more than 400 Sentani people, mainly from the eastern lake villages, work and live in Hollandia, their relatives, when coming to the capital for business or amusement, frequently spend the night there. Sleeping in the gardens at night hardly occurred at all in the Lake Area at the start

of the experiment. This habit is of some importance in the five inland villages of the Surrounding Area.

The Nimboran Control Area merges, without natural borders, into the adjacent district. All the villages are land villages. Genjem is the central village. The habit of sleeping in the gardens is of some importance in the Control Area.

Three languages are spoken in the experimental and control areas: one in the villages of the Lake Area, another in the inland villages of the Surrounding Area, and a third in the Nimboran. The inhabitants of the Nimboran have little or no contact with the Sentani; those in the inland villages are related to people living in the eastern half of the Grimé Plain, and to people along the coast. They pay regular visits to these areas.

e. Demography

Every inhabitant of the Lake Area was registered, and scrupulous care was taken to include practically every one in the card-index system. In the Control Area only the children were registered, but here perfection was not the aim. The date of birth of many of the children was obtained from the Mission registers. In conformity with the method worked out by VOORS (1956), we made notes of the last erupted tooth in the left upper jaw of these children and calculated the average age of the children with the same dental formula. With the help of the figures obtained in this way the age of the children whose birth-date was not exactly known, was estimated. The age of adults was estimated in every village with the help of local people, using calendars of local events.

Since a survey by SWELLENGREBEL & SWELLENGREBEL (1948) it was known that the Lake Area consisted, from a malariological point of view, of two different parts. This will be discussed later; but for the purpose of the experiment under consideration the demographic constellation was worked out separately for these two parts. The composition of the population of the region with the higher (holo-endemic) degree of malaria transmission can be deduced from Table XI A, that with the lower (meso-endemic) from Table XI B (see also para. C). The figures represent the situation on 1 January 1954, i.e. before the experiment was started. From the tables it can be easily concluded that on an average the holo-endemic villages were smaller than the meso-endemic ones, but that otherwise the percentages applying to the various age-groups corresponded strikingly well.

f. *Health conditions*

Morbidity and mortality figures from the time before residual insecticides were applied are not available for the areas. Drugs were easily obtainable from dispensaries and hospitals in both the Sentani- and the Nimboran areas; moreover, a motor-launch of the Government Health Service visited lake villages twice a week, but (except for injections against yaws) treatment was not sought with regularity and had little influence on malaria morbidity.

TABLE XIA

COMPOSITION OF THE POPULATION IN THE HOLO-ENDEMIC PART OF THE LAKE AREA.

Age - groups / Name of villages:	Dojo	Sosiri	Jaconde	Dondai	Kwade-ware	Simporo	Baberong-ko	Ifar Ba-berongko	Jaboeai	Sere	Netar	Poeé	Total	Total ♂	Total ♀	Per cent. of total
0— 2 months	10	7	3	—	6	4	6	3	3	1	2	1	46	19	17	
3— 5 „	12	3	2	1	—	3	3	2	1	3	1	5	36	15	21	
6— 8 „	4	2	3	1	—	1	2	1	2	1	—	4	21	8	13	
9—11 „	2	2	—	—	1	2	2	3	2	2	—	—	16	10	6	
Total under 1 year	28	14	8	2	7	10	13	9	8	7	3	10	119	52	67	5
1 year	26	14	4	7	7	9	13	11	15	5	4	7	122	59	63	5
2 years	14	7	4	1	3	7	5	6	7	4	6	6	70	34	36	3
3 „	21	4	6	3	2	4	8	4	2	1	2	3	60	24	36	2.5
4 „	25	10	4	5	7	3	5	5	9	7	6	6	92	52	40	4
5 „	13	10	2	3	5	10	7	7	3	3	3	10	76	39	37	3
Total 1—5 years	99	45	20	19	24	33	38	33	36	20	21	32	420	208	212	17.5
6—10 years	60	37	17	16	15	17	34	28	24	13	14	19	294	160	134	12
11—15 „	55	26	14	17	16	21	38	25	16	10	18	14	270	136	134	11
16—20 „	56	17	9	18	14	27	27	33	18	10	15	19	263	145	118	10.5
21—25 „	33	14	14	7	14	5	27	14	11	12	16	4	171	77	94	7
26—30 „	39	16	14	17	19	13	17	16	29	13	10	11	214	114	100	9
31—35 „	31	11	4	10	8	20	13	18	17	11	10	17	170	78	92	7
36—40 „	42	16	4	5	12	11	23	10	11	7	9	19	169	81	88	7
41—45 „	19	13	12	2	7	10	8	19	7	3	10	8	118	64	54	5
46—50 „	26	14	4	9	3	11	6	13	10	1	11	14	122	46	76	5
51—55 „	7	5	2	5	5	1	6	11	6	9	5	6	68	23	45	3
56—60 „	8	2	2	1	—	2	1	5	3	4	5	1	34	13	21	1
61—> „	—	—	—	—	—	—	—	—	1	—	—	—	1	—	1	—
Total	503	230	124	12	144	1881	251	234	197	120	147	174	2433	1197	1236	100

TABLE XI B

COMPOSITION OF THE POPULATION IN THE MESO-ENDEMIC PART OF THE LAKE AREA.

Age-groups / Name of villages :	Jobe	Ifar besar	Ifar ketji l	Siboiboi	Poejo besar	Poejo ketjil	Asei besar	Asei ketjil	Ajapo	Total	Total ♂	Total ♀	Per cent. of total
0— 2 months	2	8	10	4	8	3	9	2	13	59	27	32	
3— 5 „	3	10	9	4	5	2	4	1	8	46	23	23	
6— 8 „	3	6	2	3	1	4	11	2	11	43	16	27	
9—11 „	1	6	1	3	2	—	3	1	8	25	12	13	
Total under 1 year	9	30	22	14	16	9	27	6	40	173	78	95	4
1 year	9	21	27	13	19	8	30	7	45	179	86	93	4
2 years	8	30	13	13	15	13	24	8	38	162	78	84	4
3 „	10	18	14	9	16	8	25	6	36	142	76	66	3.5
4 „	10	25	20	11	19	5	33	9	22	154	80	74	3.5
5 „	8	16	12	18	12	7	27	6	17	123	61	62	3
Total 1—5 years	45	110	86	64	81	41	139	36	158	760	381	379	18
6—10 years	42	69	91	37	59	39	76	27	112	552	274	278	13
11—15 „	29	85	50	41	48	35	74	25	95	482	257	225	11.5
16—20 „	35	86	64	40	40	38	88	21	113	525	249	276	13
21—25 „	22	39	21	30	41	17	74	19	37	300	151	149	7
26—30 „	22	36	21	15	35	30	51	14	93	317	148	169	7.5
31—35 „	16	29	18	14	14	21	43	16	70	241	128	113	6
36—40 „	19	68	38	27	23	15	50	20	64	324	160	164	8
41—45 „	10	27	29	21	26	18	13	3	51	198	81	117	5
46—50 „	7	26	21	18	22	16	24	8	40	172	83	99	4
51—55 „	2	5	5	5	8	2	18	4	16	65	35	30	1.5
56—60 „	2	4	3	2	18	6	16	1	10	62	14	48	1.5
61—> „	—	2	1	2	1	—	4	2	—	13	4	9	—
Total	260	616	471	330	432	287	697	202	899	4194	2043	2151	100

In 1955, the Division for Mother- and Child Health started activity in the Lake Area, during the time of our observation still confined to the eastern part. In addition, a nurse of this division was stationed in the Nimboran Control Area.

Thanks to treatment, active yaws was apparent only in a low percentage of the populations, somewhat more in the Nimboran than in the Lake Area. In 1955 a mass anti-yaws campaign was launched by the Yaws Control Division in both areas, and practically every inhabitant received a penicillin (PAM) injection. Since then no yaws has been seen in the areas.

Tropical ulcers were regularly seen. Tinea imbricata is widespread. Since 1948 I observed in Hollandia and the surrounding districts epidemics of influenza, morbilli, varicellae, parotitis epidemica, and isolated cases of poliomyelitis. Both forms of dysentery are endemic, with occasional minor epidemics. Pneumonia is often seen, leprosy only in imported cases. Tuberculosis, formerly only occasionally encountered among the indigenous people, is spreading rapidly, becoming one of the major public health problems. Clinical cases of typhoid and scrub typhus are unknown in the native population in the experimental and control areas. Filariasis is a problem in the Nimboran; in the Sentani basin it is seen less frequently.

g. *State of nutrition*

The state of nutrition of the inhabitants of both areas is certainly not ideal, but on the other hand not alarmingly bad. Sago, complemented by various tubers, is the staple food and readily available in sufficient quantity. Caloric deficiency need not therefore be present. Nevertheless it may be found sometimes, when by carelessness, illness, or social circumstances (work outside the villages, unmarried mothers, widows) not enough food is collected from sago-marshes or vegetable gardens. Protein deficiency is most threatening, especially in the Nimboran. The Sentani Lake regularly provides small fish for the daily diet, probably not always in sufficient quantity, but of high quality.

In February 1954, Dr LUYKEN (LUYKEN & LUYKEN-KONING, 1956) kindly made a dietary survey, at our request, in two villages in the Lake Area, one village (Simporo-Baberongko) in the holo-endemic part, the other (Ajapo) in the meso-endemic part. In each village about 50 families were included in the survey. During the few days of their observations the intake of proteins, calcium, iron, and various vitamins was too small when compared with standards. However, because these standards were calculated relatively high, the investigators concluded that one need not worry overmuch about the diet of the Sentani.

OOMEN & MALCOLM (1956) examined the nutritional status of several hundreds of infants and toddlers in the Lake Area early in 1956, two years after the first insecticide spraying. Compared with children investigated by these authors in other parts of New Guinea, the state of nutrition at Sentani took a favourably intermediate place. Only a few cases occurred

in which minor symptoms of malnutrition were seen, including a pair of twins.

In the Nimboran no such investigations have been made. One may imagine, however, that the diet there would be poorer in animal proteins. Fish is practically unknown in the valley. Freshwater mussels are scarce and so are tame pigs and goats. The main sources of animal proteins are wild pigs and birds provided by hunting, and therefore are certainly not daily in the menu. It may be expected from this that the nutritional status of the inhabitants of the Nimboran will be inferior to that of the Lake Area people. This assumption is supported when we compare the average weights and heights of about 50 men and 50 women from each area.

	Number	Average weight in kg	Average height in cm
Sentani men	50	58.1 ± 0.8	160.2 ± 0.8
Nimboran men	50	54.3	159.7
Sentani women	50	46.7 ± 0.9	149.7 ± 0.8
Nimboran women	47	44.2	149.7

Unfortunately the individual records from the Nimboran are lost, and it is therefore impossible to calculate whether the differences in weight, found in connection with practically equal height, are significant. The figures would seem to indicate that they are.

Comparison of records of heights and weights of infants and children from the Lake Area and from the Nimboran Control Area is possible from Table XXVII and from the Figures IX and X. These also make it probable that nutrition is better in the former than in the latter area.

Infants are, as a rule, completely breast-fed for at least six or seven months. In the Sentani basin the habit prevails to give very young children regularly a piece of "pepeda" (= sago paste containing 85% water), the size of a marble, "to get them used to the taste".

B. DESCRIPTION OF THE FIELD EXPERIMENT

a. *Spleen and parasite surveys*

Spleens were examined and thick Giemsa-stained blood films made of a representative sample of the population in the Lake Area before spraying, i.e. once between October and December 1953 when all ages were included in the survey, while in February, March and April 1954, the children only were examined once more for malaria, on the day their village was to be sprayed. In each village about four months elapsed between the two surveys.

After the spraying operation, new-born infants were regularly examined for malaria at intervals of one or two months. These infants are called "control infants". One year and two years after the first application of insecticides complete re-surveys of all ages were made.

A survey was made in the five inland villages of the Surrounding Area before spraying, in February 1954, while the infants were examined on several occasions after spraying.

In the Control Area complete surveys were made in May 1953, February 1954, July 1954, and July 1955. Moreover, children under one year old were examined for malaria in October 1954; under three in February 1955, and under twelve in May 1955 (parasites only). Since then this area has become an experimental area for a new project, this time with dieldrin as residual insecticide. So far only infants born after the first spraying in this area have been examined for malaria. All the surveys in the various areas are conveniently arranged in Table XII.

TABLE XII

SPLEEN- AND PARASITE SURVEYS MADE IN RELATION TO THE EXPERIMENT.

Date	Lake Area	5 inland villages Surrounding Area	Nimboran Control Area
1953			
May			all ages
Oct.–Dec.	all ages		
1954			
Jan.–March	infants & children 1st spraying		
Febr.		all ages 1st spraying	all ages
May	infant control		
July	infant control		all ages
Sept.	infant control		
Oct.			infants only
Dec.	infant control	infant control	
1955			
Febr.	infant control		under 3 years
Febr.–March	all ages (one year after 1st spraying)		
May			under 12 years (parasites only)
June	infant control		
July			all ages 1st spraying
August	infant control	infant control	
Oct.			infant control
Dec.			infant control
1956			
Jan.–March	all ages (two years after 1st spraying)		
Febr.		infant control	
July	infant control		infant control
Oct.	infant control		infant control

Spleens were always palpated with the subject in a recumbent position, and recorded according to Schüffner's classification. Only thick Giemsa-stained blood films were made. Infections are described as "heavy", when every microscopic field, apart from those along the border, is positive, which indicates, for the films we make, about 500 or more parasites per cmm of blood. Parasite counts were made only once, viz. of the blood-slides of the Nimboran survey of July 1955; but prof. N. H. SWELLENGREBEL kindly put the figures of the unpublished parasite counts of his Sentani survey of 1947 at my disposal.

b. *Entomological surveys*

The small staff collected as much entomological data as possible, and later added to these when the personnel had been increased and better trained. In 1953, before spraying, mosquitoes were collected mainly in Dojo, one of the western holo-endemic lake villages, while on one occasion collections were organized for a period of ten days on three of the meso-endemic islands in the lake. In 1954, after the spraying was begun, the catches in Dojo were continued at regular intervals, but they were supplemented by catches in the control area. Care was taken that in both places catches were made approximately at the same time.

In 1955, collections were made much more frequently in the Nimboran Control Area than in the Lake Area, as the bionomics of the local mosquitoes were studied. Part of the results of all these collections has already been discussed in Chapter I.

c. *Other investigations*

It seemed to me of importance to collect, apart from the malariometric indices proper, some other objective signs of a possible improvement of health conditions by insecticide spraying. With the aid of the card-index system we therefore kept a record of births and deaths in the Lake Area. Moreover a large number of weighings and measurements of heights of infants and children were performed before and after spraying, both in the Lake Area and in the Control Area.

d. *Sprayings*

To avoid as far as possible that inhabitants of the Lake Area would be infected outside their villages once they had been sprayed, not only the houses in the Lake Area but also those of the Surrounding Area were treated with insecticide. The first spraying was done between January 4 and April 9, 1954, with a suspension of 5 per cent. DDT wettable powder, sometimes replaced in non-native houses by 5 per cent. DDT in kerosene. An average of 2.4 grams was used to make sure that about 2 grams of technical DTT was applied per square metre. Successive sprayings are being done at intervals of six months. The Lofstrand sprayer, type 250

TABLE XIII

SPLEEN- AND PARASITE SURVEY LAKE AREA I N OCT. - NOV. - DEC., 1953, BEFORE SPRAYING.

Part of area	Age-groups	SPLEENS: Number	Spleen size. Schüffner's classification: I	II	III	IV	V	>V	Number palpable	Spleen rate %	Average spleen	Average enlarged spleen	PARASITES: Number of slides	Number positive	Absolute par. rate %	Mixed infections	All spec. inf. rate %	P. falcipar. Number	P. falcipar. Gam.	P. vivax Number	P. vivax Gam.	P. malariae Mümber	P. malariae Gam.	Non classif.	Heavy inf. rate %
A. Holo-endemic part	0- 2 mnths.	22	4	1	1	—	—	—	6	27	0.4	1.5	22	1	4	—	4	—	—	1	—	—	—	—	4
	3- 5 „	17	3	1	5	2	—	—	11	65	1.6	2.5	17	9	53	3	70	6	—	3	1	3	—	—	41
	6- 8 „	17	4	3	3	2	—	—	12	70	1.6	2 2	17	10	59	8	106	6	1	6	2	6	4	—	29
	9-11 „	11	2	3	1	—	1	—	7	64	1.4	2.3	11	9	82	4	118	5	—	6	2	2	1	—	36
	1 year	96	13	30	20	14	9	—	86	88	2.4	2.7	96	81	84	41	123	33	6	50	9	39	10	—	46
	2 years	60	12	14	18	9	—	1	54	90	2.3	2.5	61	49	80	22	118	23	6	27	5	21	6	—	46
	3- 5 „	180	24	60	57	28	4	1	174	97	2.5	2.6	179	131	73	47	99	68	6	33	6	77	15	—	25
	6- 8 „	189	32	90	50	15	1	—	188	99	2.3	2 8	174	115	66	23	73	61	1	18	1	59	12	—	9
	9-11 „	125	24	42	36	20	1	1	124	99	2.5	2.5	123	57	46	4	49	27	2	12	—	22	2	—	2
	12-14 „	94	10	32	38	12	1	—	93	99	2.6	2.6	90	32	35	5	41	15	1	8	2	14	2	—	2
	15-24 „	232	72	75	42	10	6	—	205	88	1.8	1.9	223	64	29	5	31	40	1	11	1	18	2	—	0
	25-34 „	257	80	88	35	19	10	—	232	90	1.9	2.1	257	68	26	1	27	37	1	10	—	22	2	—	1
	35-44 „	167	48	58	26	8	—	—	140	84	1.6	2.0	169	47	28	1	28	30	—	6	—	12	1	—	0.5
	> 44 „	128	38	30	28	7	2	—	105	82	1 7	2.0	127	41	32	3	35	25	1	9	—	10	1	—	0
	TOTAL	1595	366	527	360	146	35	3	1437	90	2.0	2.3	1566	714	46	167	56	376	26	200	29	305	58	—	10
B. Meso-endemic part	0- 2 mnths.	26	4	1	—	—	—	—	5	19	0.2	1.2	26	3	11	—	11	2	—	—	—	1	—	—	0
	3- 5 „	22	9	3	1	—	—	—	13	59	0.8	1.4	22	3	14	1	18	1	—	1	—	2	—	—	0
	6- 8 „	26	14	1	—	—	—	—	15	58	0.6	1.1	26	1	4	—	4	1	—	—	—	—	—	—	0
	9-11 „	20	9	2	—	—	—	—	11	55	0.6	1.2	19	2	10	—	10	1	—	—	—	1	—	—	5
	1 year	109	29	10	1	—	1	—	41	38	0.5	1.4	109	14	13	1	14	2	2	9	—	4	1	—	2
	2 years	99	22	7	1	1	1	—	32	32	0.5	1.4	99	22	22	7	29	7	1	15	1	7	2	—	5
	3- 5 „	270	69	23	12	7	—	—	111	41	0.7	1.6	270	73	27	8	30	38	10	23	7	20	5	—	6
	6- 8 „	314	98	34	10	3	—	—	145	46	0.7	1.4	310	63	20	5	22	35	4	10	2	23	6	—	4
	9-11 „	241	86	26	3	2	—	—	117	49	0.6	1.3	238	52	22	5	24	32	4	8	1	17	2	—	4
	12-14 „	106	35	20	7	2	—	—	64	60	1.0	1.6	106	27	25	1	26	12	1	5	—	11	—	—	6
	15-24 „	297	103	55	13	4	1	—	176	59	0.9	1.6	296	55	19	5	27	32	3	14	1	14	3	—	4
	25-34 „	297	106	47	17	6	2	—	176	59	1.0	1.6	293	30	10	2	11	23	2	3	1	6	1	—	0.5
	35-44 „	223	71	34	13	1	1	—	120	54	0.8	1.6	224	24	11	—	11	15	2	1	—	8	—	—	0
	> 44 „	125	38	15	5	2	2	—	61	49	0.8	1.6	124	20	16	1	17	12	—	5	—	4	—	—	0
	TOTAL	2175	696	278	83	28	7	—	1087	50	0.7	1.5	2162	389	18	36	20	213	29	94	13	118	20	—	3

A.P., fitted with S.S. 8002 stainless steel teejet tip, renders good service. The walls are sprayed completely, the roofs near the eave-openings only. Special care is taken that the floor-wall junction gets enough insecticide. Galleries are included, as well as the scanty animal sheds. As a rule the underside of the houses is neglected. Whether furniture is sprayed or not depends on the quality; usually the natives do not object to it. The cooperation of the people is excellent, largely because they were instructed beforehand with the help of photographic slides and a keroscope projector. For this propaganda we owe a great debt of gratitude to the Division for Native Information of the Department of Cultural Affairs of Netherlands New Guinea.

C. MALARIOMETRIC DATA BEFORE SPRAYING

a. *Lake Area*

In the Lake Area, as noted by SWELLENGREBEL & SWELLENGREBEL (1948) and by SWELLENGREBEL (1949), malaria transmission was more intense in the western part where the villages lie along the lake shore, than in the eastern part where all but two villages are situated on small islands or on the long Ajapo peninsula, where steep slopes provide no opportunity for mosquito breeding. On those occasions when we looked for anopheline larvae, we never found a single one. The few anophelines captured there must come from the lake shore, for the greater the distance from shore, the fewer were caught during a ten-day observation period on three of the islands (see also para. E.b). It is evident that the islanders are infected almost exclusively when they spend the night ashore.

Transmission in the two eastern villages Netar and Poeé, situated along the shore of the lake, resembles that of the western villages. The highly malarious part of the Lake Area therefore comprises the villages Dojo, Sosiri, Jaconde, Dondai, Kwadeware, Simporo, Baberongko, Ifar Baberongko, Jaboeai, Sere, Netar and Poeé. Anticipating discussions in Chapter V this part will be referred to, already here, as the holo-endemic part of the Lake Area. The meso-endemic eastern part comprises the villages Jobe, Ifar, Siboiboi, Poejo I, Poejo II, Asei and Ajapo (see Map).

The results of spleen- and parasite surveys of October-December 1953 and of February-April 1954, made in the Lake Area, are reproduced in Tables XIII A and B, and Tables XIV A and B, respectively. No significant differences are noticeable between the rates found on the two occasions. It therefore seems permissible to combine the two, which is done in Tables XV A and B, in which the percentages of the various spleen sizes in each age-group are also calculated.

More large spleens were found in the holo-endemic, as compared with the meso-endemic part. In the holo-endemic part the percentage of large spleens (size III and larger) is highest in children. The spleen- and parasite rates of the holo-endemic part closely resemble those calculated by SWELLENGREBEL (1949). Our figures from the meso-endemic part are somewhat lower. It is easily seen that the western part is highly malarious.

TABLE XIV

SPLEEN- AND PARASITE SURVEY INFANTS AND CHILDREN OF THE LAKE AREA IN FEBR. - MARCH - APRIL, 1954, BEFORE SPRAYING

Part of area	Age-groups	SPLEENS											PARASITES													
		Number	Spleen size. Schüffner's classification						Number palpable	Spleen rate %	Average spleen	Average enlarged spleen	Number of slides	Number positive	Absolute parasite rate %	Mixed infections	All. spec. inf. rate %	P. falcipar.		P. vivax		P. malariae		Non classif.	Heavy inf.rate %
			I	II	III	IV	V	> V										Number	Gam.	Number	Gam.	Number	Gam.		
A. Holo-endemic part	0- 2 mnths.	22	7	3	—	—	—	—	10	45	0.6	1.3	22	6	27	1	32	5	—	2	—	—	—	—	5
	3- 5 „	25	9	6	1	3	1	—	20	80	1.6	2.0	25	8	32	2	44	3	—	6	3	2	—	—	12
	6- 8 „	15	3	4	3	1	—	—	11	73	1.6	2.2	15	10	67	2	80	3	1	6	2	3	—	—	20
	9-11 „	12	3	2	4	1	1	—	11	92	2.3	2.5	12	10	83	3	108	5	1	4	1	4	—	—	42
	1 year	122	21	33	30	17	8	—	109	89	2.3	2.6	122	98	80	35	112	51	14	46	11	40	14	5	36
	2 years	70	5	23	15	15	4	—	62	89	2.5	2.8	70	62	89	32	139	39	5	28	5	30	13	1	39
	3- 5 „	208	26	63	79	35	2	—	205	99	2.6	2.6	208	173	83	69	125	101	10	60	4	100	24	1	21
	6- 8 „	189	20	68	67	28	5	—	188	99.5	2 6	2.6	189	138	73	34	91	73	4	43	4	56	12	2	7
	9-11 „	74	7	26	27	10	2	1	73	99	2.7	2.7	74	45	61	2	65	21	—	14	1	13	—	—	3
	TOTAL	737	101	228	226	110	23	1	689	94	2.4	2.6	737	550	75	180	103	301	35	209	31	248	63	9	19
B. Meso-endemic part	0- 2 mnths.	24	7	1	—	—	—	—	8	33	0.4	1.1	24	0	0	—	0	—	—	—	—	—	—	—	0
	3- 5 „	35	7	3	3	—	—	—	13	37	0.6	1.7	35	2	6	1	9	1	—	2	—	—	—	—	0
	6- 8 „	31	7	1	—	1	—	—	9	29	0.4	1.4	31	3	8	—	8	—	—	3	—	—	—	—	0
	9-11 „	29	8	2	—	—	—	—	10	34	0.4	1.2	29	2	7	—	7	1	—	—	—	—	—	1	0
	1 year	141	14	12	5	—	—	—	31	22	0.4	1.7	141	16	11	4	15	7	5	8	4	6	1	—	5
	2 years	113	13	7	3	1	—	—	24	21	0.4	1.7	113	26	23	6	27	10	5	12	4	8	1	2	6
	3- 5 „	318	43	35	18	3	—	—	99	31	0.6	1.8	318	66	21	12	24	31	9	32	10	13	4	3	5
	6- 8 „	311	90	33	8	5	—	—	136	43	0.7	1.5	311	65	21	11	24	26	6	27	3	21	6	2	4. 5
	9-11 „	120	38	17	—	—	—	—	55	46	0.6	1.3	120	23	19	2	20	9	5	6	2	10	—	—	2
	TOTAL	1122	227	111	37	10	—	—	385	34	0.5	1.4	1122	203	18	36	21	85	30	90	23	58	12	8	4

Infants are infected at an early age, the maxima of the Absolute Parasite Rate (A.P.R.), of the All Species Infection Rate (A.S.I.R.), and of the Heavy Infection Rate (H.I.R.) falling in the 1- and 2-year age-group. In SWELLENGREBEL's survey the maximum of the A.P.R. exceeded 90 per cent.

b. *Surrounding Area*

In the five inland villages of the Surrounding Area the A.P.R., A.S.I.R. and H.I.R. are even higher, and the infants are infected earlier, as can be seen from Table XVI. The few heavy infections in the age-groups above 15 were mainly in women. Not improbably these women had only recently married from less malarious coastal areas. The relatively low A.P.R. and A.S.I.R. in the 1- and 2-year groups are probably due to drugs, recently provided by the dispensery in the area. Malaria in the inland villages will be classified as holo-endemic.

c. *Nimboran Control Area*

In the Nimboran Control Area, malaria will also be classified as holo-endemic. Particulars are given in Tables XVII A and B. In these tables two surveys are recorded, widely separated in time and from different seasons. In one survey *P. falciparum* prevails, in the other *P. vivax*, but in the various rates no essential differences are observable. The other surveys also show essentially the same malariological picture and it therefore seems no use to reproduce separately the results of these surveys. In Table XVIII, however, all seven surveys are combined and the rates of each age-group calculated for the combined figures. It should be mentioned that, in the four surveys which covered all ages, *P. falciparum* and *P. vivax* each prevailed twice.

Attention is drawn to the fact that, though the tables of the separate surveys are summarized, the totals have only a relative value for comparison, because the age-groups are not represented equally in the various surveys. The combining Tables XV and XVIII also include surveys in which only the younger age-groups were examined. The rates of the totals of these tables are not calculated. They would give too false an impression.

Particulars of the malaria situation in the Lake- and Control Areas will be dealt with in Chapter V. In the present chapter figures of the surveys before spraying will be compared with results of surveys made after spraying.

D. MALARIOMETRIC DATA AFTER SPRAYING

a. *Lake Area*

The results of the two complete surveys made respectively one (1955) and two years (1956) after the first application of insecticides in the Lake Area are tabulated in Tables XIX A and B and Tables XX A and B. They must be compared with Table XV A and B, representing the malaria

TABLE XVI

SPLEEN- AND PARASITE SURVEY IN FIVE INLAND VILLAGES IN SURROUNDING AREA, FEBR. 1954, BEFORE SPRAYING

Age-groups	SPLEENS											PARASITES												
	Number	Spleen size. Schüffner's, classification						Number palpable	Spleen rate %	Average spleen	Average enlarged spleen	Number of slides	Number positive	Absolute par. rate %	Mixed infections	All spec. inf. rate %	P. falcipar.		P. vivax		P. malariae		Non classif.	Heavy inf. rate %
		I	II	III	IV	V	> V										Number	Gam.	Number	Gam.	Number	Gam.		
0- 2 mnths.	2	—	—	1	—	—	—	1	(50)			2	2		—		1	—	1	—	—	—	—	
3- 5 „	5	—	—	1	3	1	—	5	(100)			5	4		3		3	1	4	1	—	—	—	
6- 8 „	6	—	3	2	1	—	—	6	(100)	3.0	3.2	6	6	93	2	133	3	1	4	2	1	—	—	47
9-11 „	2	—	—	2	—	—	—	2	(100)			2	2		1		1	—	2	2	—	—	—	
1 year	19	1	3	4	9	2	—	19	100	3.4	3.4	19	13	68	15	147	8	3	14	4	6	4	—	63
2 years	15	1	4	5	4	1	—	15	100	3.0	3.0	15	12	80	7	127	7	—	8	1	4	3	—	47
3- 5 „	48	2	22	12	9	2	—	47	98	2.7	2.7	48	48	100	23	148	25	2	29	9	17	15	—	14
6- 8 „	32	8	17	7	—	—	—	32	100	2.3	2.3	32	25	78	7	100	12	2	14	1	6	3	—	3
9-11 „	35	8	12	8	7	—	—	35	100	2.4	2.4	35	26	74	1	77	10	1	16	2	1	—	—	6
12-14 „	23	4	16	2	1	—	—	23	100	2.0	2.0	23	10	43	—	43	4	—	6	—	—	—	—	4
15-24 „	54	24	20	7	3	—	—	54	100	1.8	1.8	54	31	57	3	63	19	3	13	3	5	3	—	4
25-34 „	53	21	23	6	2	1	—	53	100	1.8	1.8	52	22	42	3	48	10	1	13	—	2	—	—	4
35-44 „	42	21	12	4	3	1	—	41	98	1.7	1.8	42	28	69	1	69	12	1	11	1	6	2	—	0
> 44 „	29	16	5	1	3	—	—	25	86	1.4	1.6	29	15	52	+	52	6	—	7	1	2	—	—	0
TOTAL	365	106	137	62	45	8	—	358	98	2.2	2.2	364	244	67	66	85	118	15	142	27	50	30	—	11

TABLE XVII

SPLEEN- AND PARASITE SURVEYS IN NIMBORAN CONTROL AREA BEFORE SPRAYING

Date	Age-groups	SPLEENS											PARASITES													
		Number	Spleen size. Schüffner's classification						Number palpable	Spleen rate %	Average spleen	Average enlarged spleen	Number of slides	Number positive	Absolute par. rate %	Mixed infections	All spec. inf. rate %	P. falcipar.		P. vivax		P. malariae		Non classif.	Heavy inf. rate %
			I	II	III	IV	V	> V										Number	Gam.	Number	Gam.	Number	Gam.		
A. Febr. 1954	0- 2 mnths.	2	1	—	—	—	—	—	1	50	0.5	1.0	2	1	50	—	50	—	—	1	1	—	—	—	50
	3- 5 „	13	3	3	3	—	—	—	9	69	1.4	2.0	13	9	69	1	77	3	—	7	4	—	—	—	38
	6- 8 „	12	1	2	2	2	3	—	10	83	2.8	3.4	12	9	75	4	108	5	1	7	4	1	—	—	58
	9-11 „	11	—	1	2	7	1	—	11	100	3.7	3.7	11	11	100	6	154	9	5	7	5	1	—	—	63
	1 year	56	8	7	15	16	4	3	53	95	3.2	3.3	56	50	90	24	138	27	2	40	15	8	3	—	40
	2 years	56	3	16	14	15	4	—	52	93	2.8	3.0	55	48	87	21	125	24	2	24	9	21	11	—	38
	3- 5 „	103	6	31	40	20	5	—	102	99	2.8	2.9	103	89	86	34	119	48	9	53	17	22	10	—	25
	6- 8 „	120	11	51	41	14	1	—	118	98	2.5	2.5	120	98	82	27	104	37	3	55	8	33	6	—	12
	9-11 „	81	13	36	23	6	—	1	79	97	2.3	2.3	81	60	74	10	86	24	2	28	2	18	2	—	11
	12-14 „	48	8	21	14	3	—	—	46	96	2.2	2.3	47	28	58	5	69	14	5	11	2	8	2	—	2
	15-24 „	103	29	40	18	5	4	1	97	94	2.0	2.2	102	34	33	2	35	12	3	19	2	5	—	—	1
	25-34 „	258	69	103	43	12	2	2	231	90	1.8	2.0	257	100	39	5	41	34	2	53	2	18	3	—	0.5
	35-44 „	117	37	32	20	2	2	1	94	80	1.6	2.0	116	53	46	4	49	15	—	28	—	14	4	—	1
	> 44 „	26	5	6	5	2	—	—	18	70	1.5	2.2	26	6	23	—	23	1	—	3	—	2	1	—	0
	TOTAL	1006	194	349	240	104	26	8	921	92	2.2	2.4	1001	596	60	143	74	253	34	336	71	151	42	—	11
B. July 1955	0- 2 mnths.	20	9	5	1	—	—	—	15	75	1,1	1.5	20	6	30	—	30	1	1	4	3	—	—	1	10
	3- 5 „	19	3	6	2	3	2	—	16	84	2.3	2.7	20	15	75	4	95	9	4	8	5	2	1	—	25
	6- 8 „	8	1	2	1	1	3	—	8	100	3.4	3.4	10	8	80	7	150	6	1	8	6	1	1	—	70
	9-11 „	19	1	5	7	4	—	2	19	100	3.2	3.2	19	15	79	7	116	10	3	9	5	3	—	—	47
	1 year	44	6	8	11	16	1	1	43	98	3.0	3.0	44	38	86	23	139	28	12	22	8	11	2	—	48
	2 years	40	3	8	13	11	1	—	36	90	2.7	3 0	40	38	95	24	155	32	7	14	8	14	4	2	40
	3- 5 „	98	5	24	53	13	1	1	97	99	2.8	2.8	98	91	93	63	157	65	6	35	14	53	16	1	31
	6- 8 „	104	4	57	33	6	3	—	103	99	2.5	2.5	104	87	84	40	122	57	8	29	10	38	13	3	18
	9-11 „	74	13	38	21	2	—	—	74	100	2.5	2.5	72	51	71	17	94	34	4	16	4	15	4	3	12
	12-14 „	60	12	23	21	2	1	—	59	98	2.2	2.3	60	39	65	5	73	27	—	6	—	11	2	—	7
	15-24 „	47	15	22	7	2	—	—	46	98	1.9	1.9	46	27	58	4	67	18	2	4	—	7	1	2	4
	25-34 „	118	45	41	19	2	2	—	109	92	1.7	1.8	119	38	32	6	37	27	4	11	2	6	1	—	1
	35-44 „	67	28	24	9	1	1	—	63	94	1.7	1.8	68	24	35	2	38	10	2	4	—	12	—	—	0.
	> 44 „	52	22	15	4	1	—	1	43	83	1.4	1.7	53	16	30	5	40	9	—	6	1	6	—	—	2
	TOTAL	770	167	278	202	64	15	5	731	95	2.2	2.3	773	493	64	207	90	333	54	176	66	179	45	12	16

TABLE XVIII

COMBINED RESULTS OF SEVEN SPLEEN- AND PARASITE SURVEYS IN NIMBORAN CONTROL AREA BEFORE SPRAYING

Age-groups	SPLEENS																PARASITES												
	Number	Spleen size. Schüffner's classification												Number palpable	Spleen rate	Average spleen	Average enlarged spleen	Number of slides	Number positive	Absolute par. rate	Mixed infections	All spec inf. rate	P. falcipar.		P. vivax		P. malariae		Non classif.	Heavy inf. rate
		I		II		III		IV		V		> V											Number	Gam.	Number	Gam.	Number	Gam.		
		No.	%	No.	%	No.	%	No.	%	No.	%	No.	%		%					%		%								%
0- 2 mnths.	64	23	47	9	18	12	24	3	6	1	2.5	1	2.5	49	76	1.6	2.0	81	31	38	12	52	12	2	23	13	7	2	1	24
3- 5 „	82	14	20	21	30	16	23	15	21	4	6	—	—	70	85	2.2	2.6	88	66	75	29	108	31	10	48	25	16	10	—	49
6- 8 „	67	7	11	14	23	15	25	14	23	11	18	—	—	61	91	2.8	3.1	82	67	82	28	121	37	11	51	27	11	6	—	46
9-11 „	55	3	5	11	20	18	34	17	31	4	7	2	3	55	100	3.3	3.3	64	57	89	40	153	43	17	43	21	12	5	1	62
1 year	233	29	14	42	20	57	27	62	29	16	6	7	4	213	92	2.8	3.1	267	240	90	154	148	154	42	167	64	74	22	—	53
2 years	223	14	7	50	24	70	33	65	30.5	11	5	1	0.5	211	94	2.9	3.1	250	234	94	172	162	160	28	118	37	126	49	2	47
3- 5 „	409	35	8	120	30	166	42.5	67	17	10	2	1	0.5	399	97	2.7	2.8	488	444	91	272	147	276	38	225	62	214	72	1	31
6- 8 „	398	56	14	179	46	118	30	33	8	4	2	—	—	390	98	2.3	2.4	450	374	83	168	120	206	17	173	35	160	38	3	16
9-11 „	295	64	24	129	43	72	26	17	6	1	0.5	1	0.5	284	96	2.1	2.2	321	231	72	70	93	125	12	95	10	78	15	3	10
12-14 „	207	58	30	77	40	50	26	8	3	2	1	—	—	195	94	2.0	2.1	205	122	60	24	71	66	7	47	5	33	5	—	4
15-24 „	394	122	36	127	39	59	18	15	4.5	5	2	1	0.5	329	83	1.6	1.9	391	159	41	17	45	74	10	60	2	40	6	2	1
25-34 „	780	256	41	226	36	108	17	27	4	6	1.5	2	0.5	625	80	1.5	1.9	778	257	33	31	37	122	8	110	7	56	9	—	0.5
35-44 „	364	124	45	98	36	40	14.5	8	3	3	1	2	0.5	275	76	1.4	1.8	360	130	36	10	39	41	2	50	0	49	6	—	1
> 44 „	109	31	42	27	37	12	16	3	5	—	—	—	—	73	67	1.2	1.8	110	36	33	5	37	18	2	13	1	10	1	—	1
TOTAL	3680													3229				3935	2448		1032		1365	206	1223	309	886	246	12	

situation before spraying. From Tables XVII A and B it is seen that in the Nimboran Control Area, the malaria situation between February 1954 and July 1955 had practically remained the same.

To facilitate comparison, the main points of the various tables are arranged more conveniently in Table XXI. For this table the averages of the Tables XV and XVIII have been used. The changes in the various rates after spraying may be easily seen from Figures I to VII incl.

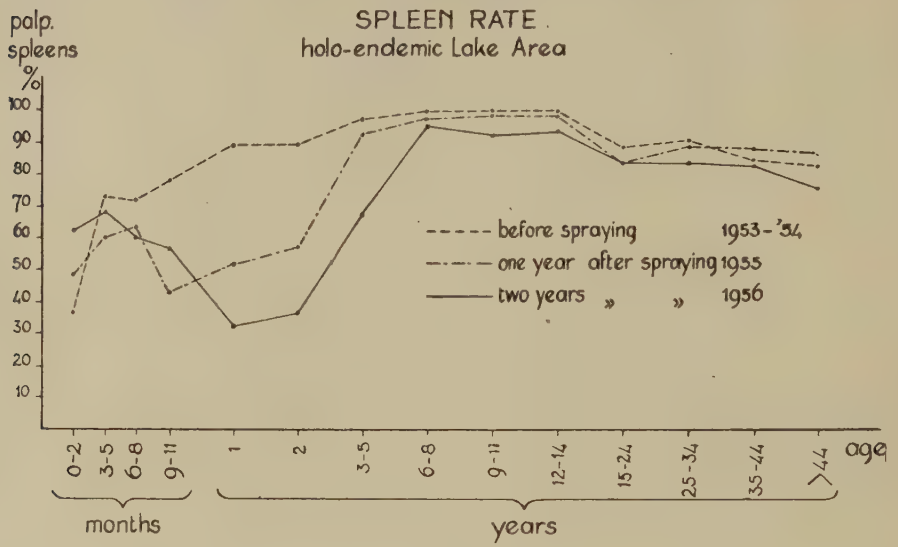


FIG. I.

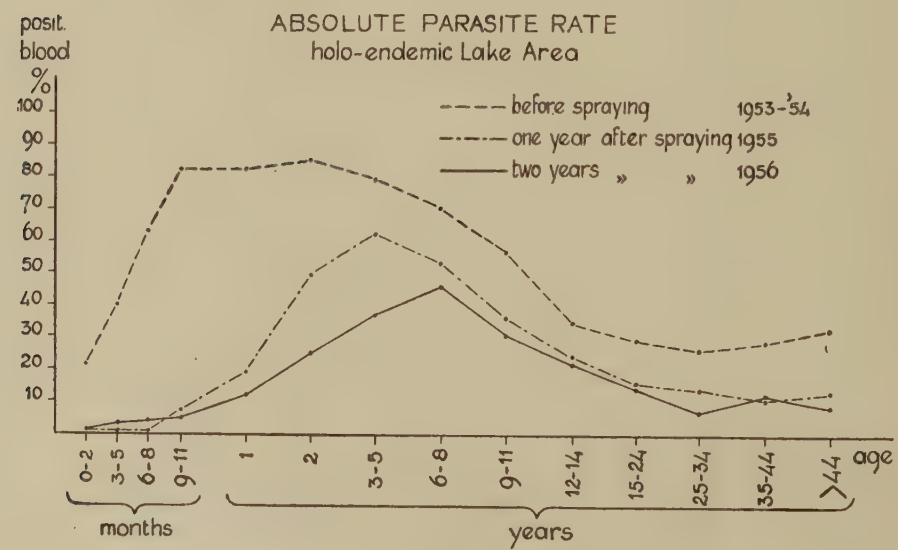


FIG. II.

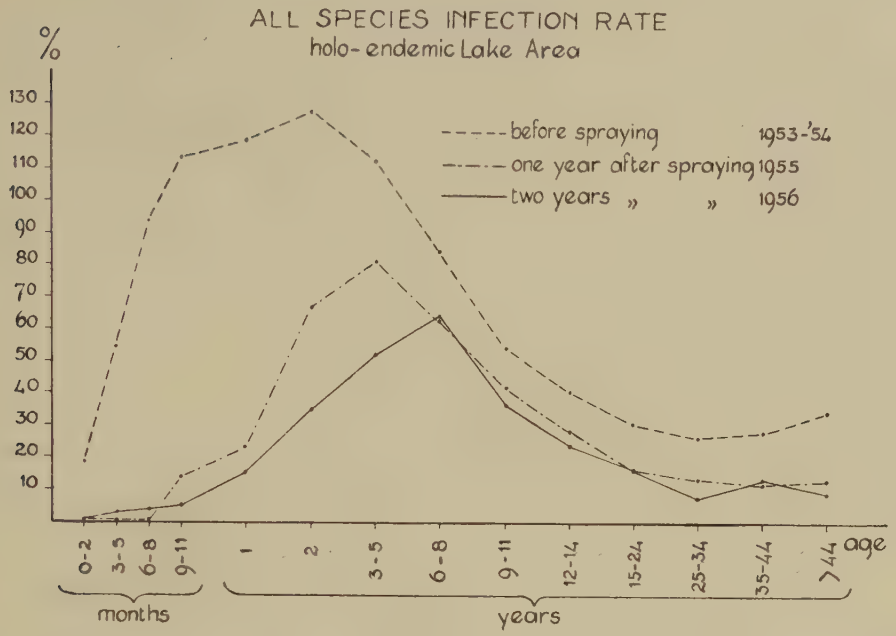


FIG. III.

1. *Holo-endemic part of Lake Area*

It is plain from the various tables and diagrams that considerable improvement was achieved in the figures of the holo-endemic part of the Lake Area, especially in the A.P.R., the A.S.I.R. and the H.I.R.

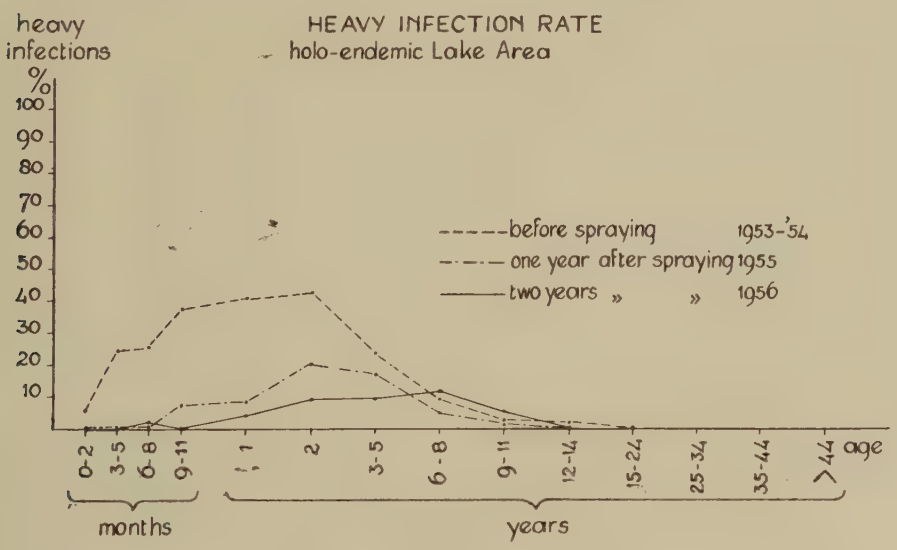


FIG. IV.

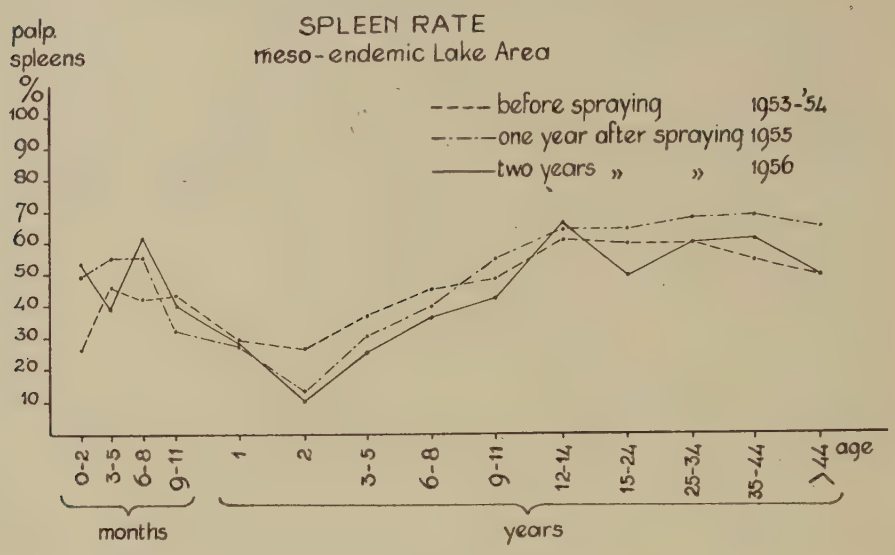


FIG. V.

The spleen rate shows a marked improvement only in toddlers and young children, not so much in infants and age-groups above 5 years, though the decrease is significant up to and including the 12—14-year group. This peculiarity of the spleen rate will be discussed in more detail in Chapter V. I would here only remark that the spleen rate of infants is no yardstick for malaria, and that the spleens of older Papuans, once they have been enlarged by malaria for some years, show little tendency to retract again below the costal margin. Nevertheless the average spleen sizes decreased not inconsiderably.

The figures of the A.P.R. show that infants remained almost free of infection, but more so in the first than in the second year after spraying. The top of the curves of this rate moved to the right (Figure II), and decreased from 85% ± 3%, through 62% ± 4% to 46% ± 3%. The difference between 85 and 62 is more than five times, that between 62 and 46 more than three times the standard error of difference. The decreases are therefore significant. Moreover, the decreases one year after spraying are significant in all age-groups, apart from that of 12—14-years. The decreases between the percentages of one and of two years after spraying are significant in the 2-year, 3—5-year, 9—11-year, and 25—34-year group only.

The shifts of the tops of the A.P.R. and the A.S.I.R. from the 2-years group before, to the 3—5-year group one year after spraying (Figures II and III) are logical. That one year later there is a shift to the 6—8-year group is not completely clear. It may be that by the diminution of infections, the turn of the balance between parasitaemia and immunity in

favour of the latter (which is always seen in communities permanently exposed to malaria infections and the greater the risk, the earlier it occurs) already started to be displaced to older age-groups. This would be the first indication of transformation of the two curves into a shape typical of that prevailing in areas of low endemicity.

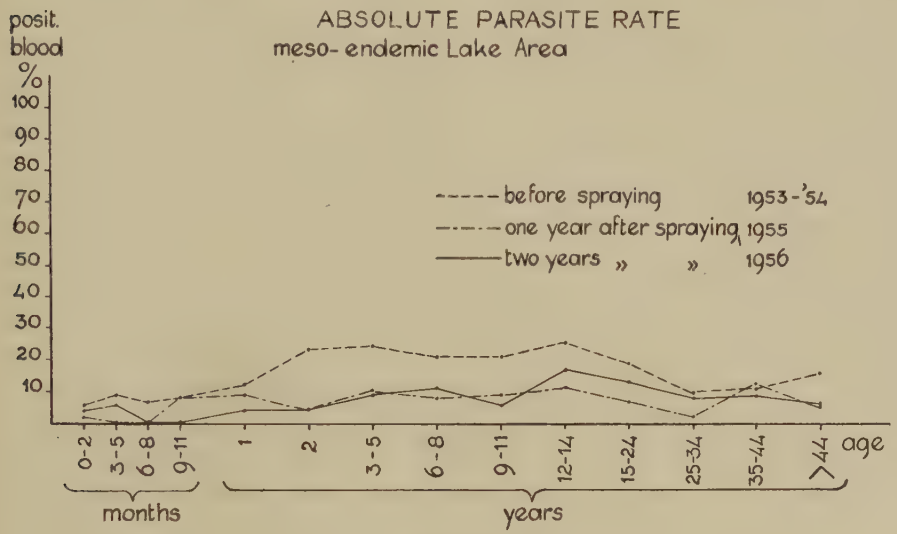


FIG. VI.

The number of mixed infections was reduced absolutely and relatively, by which the divergence between the A.P.R. and the A.S.I.R. became less pronounced.

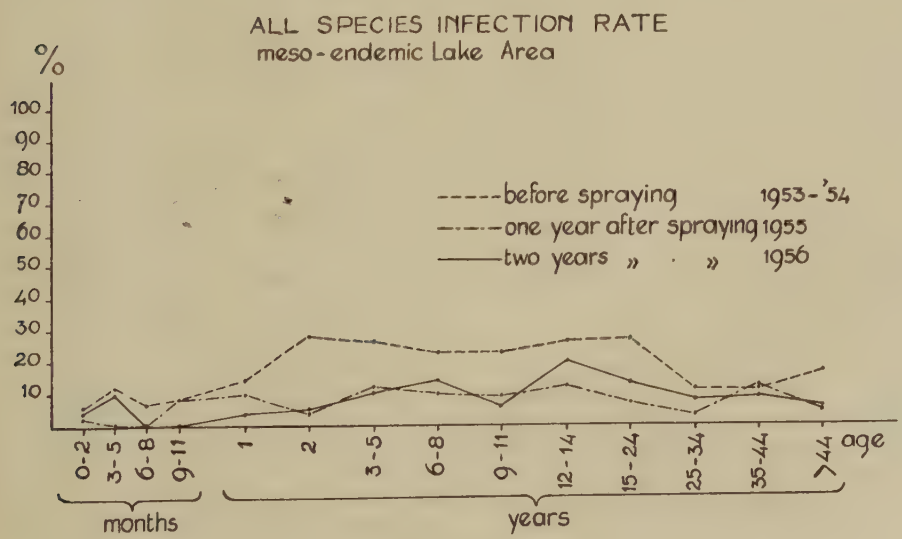


FIG. VII.

TABLE XIX

SPLEEN- AND PARASITE SURVEY IN LAKE AREA IN FEBRUARY - MARCH 1955, ONE YEAR AFTER SPRAYING

Part of area	Age-groups	SPLEENS: Number	Spleen size. Schüffner's classification: I	II	III	IV	V	>V	Number palpable	Spleen rate %	Average spleen	Average enlarged spleen	PARASITES: Number of slides	Number positive	Absolute parasite rate %	Mixed infections	All. spec. inf. rate %	P. falcipar. Number	Gam.	P. vivax Number	Gam.	P. malariae Number	Gam.	Non classif.	Heavy inf. rate %
A. Holo-endemic part	0- 2 mnths.	29	11	3	—	—	—	—	14	48	0.6	1.2	29	—	0	—	0	—	—	—	—	—	—	—	0
	3- 5 „	20	11	1	—	—	—	—	12	60	0.6	1.8	20	—	0	—	0	—	—	—	—	—	—	—	0
	6- 8 „	19	11	1	—	—	—	—	12	63	0.7	1.8	19	—	0	—	0	—	—	—	—	—	—	—	0
	9-11 „	14	4	2	—	—	—	—	6	43	0.6	1.3	14	1	7	1	14	1	—	1	1	—	—	—	7
	1 year	74	24	8	6	—	—	—	38	51	0.8	1.5	74	14	19	3	23	7	—	4	2	6	—	—	8
	2 years	96	20	20	8	5	2	—	55	57	1.2	2.0	95	47	49	17	67	20	8	13	3	31	10	—	20
	3- 5 „	194	49	56	46	23	4	—	178	92	2.1	2.3	194	121	62	37	81	48	14	22	5	88	16	—	17
	6- 8 „	192	46	79	43	17	1	—	186	97	2.1	2.3	192	102	53	19	63	25	1	15	1	81	5	—	5
	9-11 „	125	30	47	34	11	—	—	122	98	2.2	2.2	125	45	36	8	42	16	1	14	2	23	2	—	2
	12-14 „	86	28	38	14	4	—	—	84	98	1.9	1.9	86	21	24	4	29	5	—	4	—	16	—	—	1
	15-24 „	131	40	47	17	5	—	—	109	83	1.6	1.6	132	21	16	1	17	4	1	6	—	12	1	—	1
	25-34 „	146	61	45	15	7	—	—	128	88	1.5	1.8	147	21	14	—	14	5	—	—	—	15	—	1	1
	35-44 „	98	24	33	22	5	1	—	85	87	1.8	2.1	97	11	11	1	12	4	—	1	—	7	—	—	0
	> 44 „	77	31	15	16	3	1	—	66	86	1.6	1.9	77	10	13	—	13	3	1	1	—	5	—	1	0
	TOTAL	1301	390	395	221	80	9	—	1095	84	1.7	2.0	1301	414	32	91	39	138	26	81	14	284	34	2	6
B. Meso-endemic part	0- 2 mnths.	51	16	7	1	1	—	—	25	49	0.7	1.5	51	1	2	—	2	—	—	—	—	1	—	—	0
	3- 5 „	20	9	2	—	—	—	—	11	55	0.6	1.2	20	—	0	—	0	—	—	—	—	—	—	—	0
	6- 8 „	27	10	5	—	—	—	—	15	55	0.7	1.3	27	—	0	—	0	—	—	—	—	—	—	—	0
	9-11 „	25	5	1	2	—	—	—	8	32	0.5	1.6	25	2	8	—	8	1	—	1	—	—	—	—	0
	1 year	65	13	5	—	—	—	—	18	27	0.4	1.3	65	6	9	1	10	2	1	2	1	3	1	—	0
	2 years	75	9	1	—	—	—	—	10	13	0.1	1.1	75	3	4	—	4	2	1	1	—	—	—	—	1
	3- 5 „	171	38	11	2	—	—	—	51	30	0.4	1.3	171	18	10	3	12	2	—	8	2	11	2	—	0.5
	6- 8 „	271	87	19	2	1	—	—	109	40	0.5	1.2	271	23	8	3	10	8	2	7	2	11	1	—	1
	9-11 „	225	99	20	2	—	—	—	121	54	0.6	1.2	225	21	9	—	9	5	—	10	2	5	3	1	1
	12-14 „	83	36	9	6	1	—	—	52	63	0.9	1.5	84	9	11	1	12	2	1	5	—	3	2	—	1
	15-24 „	91	41	12	4	—	—	—	57	63	0.8	1.3	95	7	7	—	7	2	1	2	—	2	—	1	1
	25-34 „	81	37	14	3	—	—	—	54	67	0.9	1.4	82	2	2	1	3	—	—	1	—	1	—	—	0
	35-44 „	93	45	12	3	3	—	—	63	68	1.0	1.4	93	11	12	—	12	6	1	5	—	1	—	—	0
	> 44 „	64	28	11	2	—	—	—	41	64	0.9	1.4	66	3	5	—	5	1	—	1	—	1	—	—	0
	TOTAL	1342	473	129	27	6	—	—	635	47	0.6	1.3	1350	106	8	9	8.5	31	7	43	7	39	9	2	1

SPLEEN- AND PARASITE SURVEY IN LAKE AREA IN JAN. - FEBR. - MARCH 1956, TWO YEARS AFTER SPRAYING

Part of area	Age-groups	SPLEENS: Number	Spleen size. Schüffner's, classification: I	II	III	IV	V	> V	Number palpable	Spleen rate %	Average spleen	Average enlarged spleen	PARASITES: Number of lides	Number positive	Absolute parasite rate %	Mixed infections	All. spec. inf. rate %	P. falcipar. Number	P. falcipar. Gam.	P. vivax Number	P. vivax Gam.	P. malariae Number	P. malariae Gam.	Heavy inf. rate %
A. Holo-endemic part	0- 2 mnths.	42	22	3	1	—	—	—	26	62	0.7	1.2	42	—	0	—	0	—	—	—	—	—	—	0
	3- 5 „	34	17	16	—	—	—	—	23	68	0.8	1.3	34	1	3	—	3	1	—	—	—	—	—	0
	6- 8 „	52	21	7	2	1	—	—	31	60	0 9	1.4	53	2	4	—	4	1	1	1	—	—	—	2
	9-11 „	51	6	5	1	—	—	—	12	57	0.9	1.6	21	1	5	—	5	1	1	—	—	—	—	0
	1 year	82	15	9	2	—	—	—	26	32	0.5	1.5	82	10	12	2	15	7	2	3	3	2	1	4
	2 years	63	15	3	—	4	1	—	23	36	0.7	1.8	63	16	25	6	35	9	4	7	2	6	1	9
	3- 5 „	209	63	55	21	4	—	—	143	68	1.2	1.8	208	77	37	32	52	45	15	21	8	43	13	9
	6- 8 „	208	76	80	34	4	1	—	195	94	1.7	1.8	209	96	46	37	64	47	6	27	4	59	14	11
	9-11 „	157	61	56	25	3	—	—	145	92	1.6	1.8	157	48	30	10	37	27	2	11	—	20	1	5
	12-14 „	76	27	27	16	—	—	1	71	93	1.8	1.9	76	17	22	1	24	6	—	5	—	7	1	0
	15-24 „	232	108	67	16	2	—	—	193	83	1.3	1.5	234	34	14	6	17	12	1	12	—	16	3	1
	25-34 „	230	107	52	27	4	—	—	190	83	1.4	1.6	232	17	7	1	8	7	2	7	2	4	1	0
	35-44 „	220	93	56	22	7	2	—	180	82	1.4	1.7	221	26	12	2	13	9	—	7	1	12	1	1
	> 44 „	163	63	35	19	3	—	1	121	74	1.3	1.7	168	15	9	—	9	5	—	2	—	8	2	0.5
	TOTAL	1789	694	461	186	32	4	2	1379	77	1.3	1.7	1800	360	20	97	25	177	34	103	20	177	38	4
B. Meso-endemic part	0- 2 mnths.	28	10	5	—	—	—	—	15	53	0.7	1.3	28	1	4	—	4	1	—	—	—	—	—	0
	3- 5 „	31	6	5	1	—	—	—	12	39	0.6	1.6	31	2	6	1	10	1	—	1	—	1	—	3
	6- 8 „	23	10	4	—	—	—	—	14	61	0.8	1.3	23	—	0	—	0	—	—	—	—	—	—	0
	9-11 „	46	13	5	1	—	—	—	19	41	0.6	1.4	46	—	0	—	0	—	—	—	—	—	—	0
	1 year	97	19	8	—	—	—	—	27	28	0.4	1.3	97	4	4	—	4	3	—	1	1	—	—	1
	2 years	90	6	3	—	—	—	—	9	10	0.1	1.3	90	4	4	1	5	1	—	2	1	2	1	2
	3- 5 „	276	52	15	3	—	—	—	70	25	0.3	1.3	276	26	9	3	10	14	8	6	2	9	2	2
	6- 8 „	275	66	23	9	1	1	—	100	36	0.5	1.5	275	31	11	7	14	18	5	6	1	14	8	4
	9-11 „	252	85	18	1	—	1	—	105	42	0.5	1.2	249	14	6	—	6	8	4	1	—	5	—	2
	12-14 „	101	48	16	1	1	—	—	66	65	0.9	1.3	100	17	17	3	20	12	1	3	—	5	1	6
	15-24 „	218	82	21	3	2	—	—	108	49	0.6	1.3	221	28	13	2	13	16	3	3	—	11	1	1
	25-34 „	198	84	23	8	1	—	—	116	59	0.8	1.4	199	15	8	—	8	4	2	8	—	3	—	0
	35-44 „	205	90	24	8	—	—	1	123	60	0.8	1.4	207	18	9	—	9	12	1	1	—	5	—	1
	> 44 „	152	51	17	2	3	1	—	74	49	0.7	1.5	154	9	6	—	6	3	—	2	—	4	—	0.5
	TOTAL	1992	622	187	37	8	3	1	858	43	0.6	1.3	1996	169	8	17	9	93	24	34	5	59	13	2

TABLE XXI
COMPARISON OF MALARIOMETRIC IN DICES BEFORE AND AFTER SPRAYING

Part of area	Age-groups	Spleen rate (%)				Average spleen				Average enlarged spleen				Absolute parasite rate (%)				All species infection rate (%)				Heavy infection rate (%)			
		Nimboran control area before spraying	Lake area			Nimboran control area before spraying	Lake area			Nimboran control area before spraying	Lake area			Nimboran control area before spraying	Lake area			Nimboran control area before spraying	Lake area			Nimboran control area before spraying	Lake area		
			Before spraying	After spraying			Before spraying	After spraying			Before spraying	After spraying			Before spraying	After spraying			Before spraying	After spraying			Before spraying	After spraying	
				1 year	2 years			1 year	2 years			1 year	2 years			1 year	2 years			1 year	2 years			1 year	2 years
A. Holo-endemic part	0- 2 mnths.	76	36	48	62	1.6	0.5	0.6	0.7	2.0	1.4	1.2	1.2	38	16	0	0	52	18	0	0	24	5	0	0
	3- 5 „	85	73	60	68	2.2	1.6	0.6	0.8	2.6	2.2	1.8	1.3	75	40	0	3	108	55	0	3	49	24	0	0
	6- 8 „	91	72	63	60	2.8	1.6	0.7	0.9	3.1	2.2	1.8	1.4	82	63	0	4	121	94	0	4	46	25	0	2
	9-11 „	100	78	43	57	3.3	1.9	0.6	0.9	3.3	2.4	1.3	1.6	89	82	7	5	153	113	14	5	62	37	7	0
	1 year	92	89	51	52	2.8	2.4	0.8	0.5	3.1	2.7	1.5	1.5	90	82±2.6	19±4.5	12±3.6	148	119	23	15	53	40	8	4
	2 years	94	89	57	36	2.9	2.4	1.2	0.7	3.1	2.7	2.0	1.8	94	85±3.1	49±5.1	25±5.5	162	128	67	35	47	42	20	9
	3- 5 „	97	97	92	68	2.7	2.6	2.1	1.2	2.8	2.6	2.3	1.8	91	79±2.1	62±3.5	37±3.3	147	113	81	52	31	23	17	9
	6- 8 „	98	99	97	94	2.3	2.4	2.1	1.7	2.4	2.5	2.3	1.8	83	70±2.3	53±3.6	46±3.4	120	85	63	64	16	9	5	11
	9-11 „	96	99	98	92	2.1	2.5	2.2	1.6	2.2	2.6	2.2	1.8	72	57±3.5	36±4.3	30±3.4	93	55	42	37	10	3	2	5
	12-14 „	94	99	98	93	2.0	2.6	1.9	1.8	2.1	2.6	1.9	1.9	60	35±5.0	24±4.6	22±4.8	71	41	29	24	4	2	1	0
	15-24 „	83	88	83	83	1.6	1.8	1.6	1.3	1.9	1.9	1.6	1.5	41	29±3.0	16±3.2	14±2.4	45	31	17	17	1	0	1	1
	25-34 „	80	90	88	83	1.5	1.9	1.5	1.4	1.9	2.1	1.8	1.6	33	26±2.7	14±2.9	7±1.4	37	27	14	8	0.5	1	1	0
	35-44 „	76	84	87	82	1.4	1.6	1.8	1.4	1.8	2.0	2.1	1.7	36	28±3.5	11±3.2	12±2.2	39	28	12	13	1	0.5	0	1
	> 44 „	67	82	86	74	1.2	1.7	1.6	1.3	1.8	2.0	1.9	1.7	33	32±4.1	13±3.8	9±2.2	37	35	13	9	1	0	0	0.5
B. Meso-endemic part	0- 2 mnths.		26	49	53		0.3	0.7	0.7		1.2	1.5	1.3		6	2	4		6	2	4		0	0	0
	3- 5 „		46	55	39		0.7	0.6	0.6		1.5	1.2	1.6		9	0	6		12	0	10		0	0	3
	6- 8 „		42	55	61		0.5	0.7	0.8		1.2	1.3	1.3		7	0	0		7	0	0		0	0	0
	9-11 „		43	32	41		0.5	0.5	0.6		1.2	1.6	1.4		8	8	0		8	8	0		2	0	0
	1 year		29	27	28		0.4	0.4	0.4		1.5	1.3	1.3		12±2.0	9±3.4	4±4.0		14	10	4		4	0	1
	2 years		26	13	10		0.4	0.1	0.1		1.6	1.1	1.3		23±2.7	4±2.3	4±2.1		28	4	5		6	1	2
	3- 5 „		36	30	25		0.6	0.4	0.3		1.7	1.3	1.3		24±1.8	10±2.3	9±1.7		27	12	10		5	0.5	2
	6- 8 „		45	40	36		0.6	0.5	0.5		1.4	1.2	1.5		21±1.7	8±1.7	11±1.9		23	10	14		5	1	4
	9-11 „		48	54	42		0.6	0.6	0.5		1.3	1.2	1.2		21±2.1	9±1.9	6±1.5		23	9	6		3	1	2
	12-14 „		60	63	65		1.0	0.9	0.9		1.6	1.5	1.3		25±1.3	11±1.1	17±3.8		26	12	20		1	1	6
	15-24 „		59	63	49		0.9	0.8	0.6		1.6	1.3	1.3		19±2.3	7±2.6	13±2.3		27	7	13		1	1	1
	25-34 „		59	67	59		1.0	0.9	0.8		1.6	1.4	1.4		10±1.7	2±1.6	8±1.9		11	3	8		0	0	0
	35-44 „		54	68	60		0.8	1.0	0.8		1.6	1.4	1.4		11±2.2	12±3.4	9±4.0		11	12	9		0	0	1
	> 44 „		49	64	49		0.8	0.9	0.7		1.6	1.4	1.5		16±1.0	5±2.7	6±1.9		17	5	6		0	0	0.5

The H.I.R. decreased considerably, viz. from 10% in 1953 through 6% in 1955, to 4% in 1956.

Taking all these facts into account, it may be roughly estimated that in the two years after the first application of insecticides the parasite load in the population of the holo-endemic part of the Lake Area was reduced to about one-third of its original extent.

Interesting changes were observed in the ratio between the three species of malaria parasites during the experiment. These changes can be seen from the next table:

Survey	Per cent. P. falciparum	Per cent. P. vivax	Per cent. P. malariae
1953, before spraying	43	22	35
1955, one year after spraying	27.5	16	56.5
1956, two years after spraying	38.5	23	38.5

P. falciparum, predominant before spraying, was most reduced one year later; *P. vivax* somewhat less. A relative increase of *P. malariae* was obvious by that time. Although two years after spraying the absolute number of infections of all three species had decreased once more, their ratio was restored to practically the same values.

These facts can be explained logically by the different behaviour of the species of parasites in their human- and insect hosts. In the human host, a liver reservoir is maintained only of *P. vivax* and *P. malariae* for a considerable time after natural infections. In untreated cases, this results in parasitaemia of longer duration and in relapses. In *P. falciparum* the average period of activity after one untreated infection is less than one year. The Chesson strain of *P. vivax*, which originates from New Guinea, showed activity in volunteers for an average duration of eighteen months after an extremely large sporozoite inoculum by ten heavily infected mosquitoes (COATNEY et al., 1950). Since the authors state that the duration of the infection appeared to be related directly to the size of the inoculum, the duration in nature will usually be much shorter. BOYD (1940) found also that the dosage of sporozoites exerts a significant effect on the subsequent infection of *P. vivax*. The duration of *P. malariae* infections is estimated at longer than two years (BRUMPT, 1949).

In the insect host the extrinsic parasite cycle is shortest in *P. vivax* and longest in *P. malariae* (Chapter I, para. A.i). When the average duration of life of an anopheles population is reduced by residual insecticide spraying it may therefore be expected that the chances of transmission will be reduced most for *P. malariae*, and least for *P. vivax*.

These various facts become apparent from the changes in the ratio between the three species since spraying started. By the considerable reduction in the number of infections achieved, *P. falciparum* at first diminished most in the human population, followed by *P. vivax*. The relative prevalence of *P. malariae* must thereby increase, which, indeed,

was the fact in the survey of 1955. Later on, due to its better chances for transmission, *P. vivax* must first regain its former relative position, logically at the expense of *P. malariae*. This is evident from the figures of the ratio of the 1956 survey, which give a second indication that the malariometric indices are approaching a new and lower level.

Most probably this level has not yet been reached. Certainly the number of *P. malariae* positives will decrease further. Among the infections of *P. vivax* present in the 1956 survey, a number will also date from before spraying, because *P. vivax* infections may last for more than two years. BLACKBURN (1948) observed a parasitaemia of more than 700 days' duration in a volunteer, naturally infected with *P. vivax* in New Guinea.

In *P. falciparum* such a long duration will seldom occur. We analysed the figures for *P. falciparum* positives of the 6—8-year group of the 1956 survey (Table XX A). Of the 47 children positive for this species, 42 had been examined also in 1954 and 1955. Of these, positive for *P. falciparum* were, in

1954, 1955 and 1956:	5	1954 and 1956:	16
1955 and 1956:	4	1956 only:	17

The latter three groups may safely be regarded as new infections. Among the first group, infections from before spraying may still be present. In this case a further small reduction in the number of *P. falciparum* may be expected.

When considering the figures for gametocytes, one has to bear in mind that *P. malariae* female gametocytes are almost indistinguishable from mature trophozoites. The number of gametocytes of this species is therefore usually estimated too high, which may also have happened in our own surveys.

The numbers of gametocytes found for the three species in the various age-groups before and after spraying are given, for the holo-endemic area, in Tables XV A, XIX A and XX A. Expressed as percentages of the number of infections of each species the figures are shown in the following table.

Age-groups	P. falciparum			P. vivax			P. malariae		
	before spraying	1955	1956	before spraying	1955	1956	before spraying	1955	1956
Under 1 year	9	(0)	(66)	33	(100)	(0)	25	—	—
1 „	24	(0)	(29)	21	(50)	(100)	30	(0)	(50)
2 years	18	40	(44)	18	23	(30)	37	32	(17)
3— 5 „	9	29	33	11	23	38	22	18	30
6— 8 „	4	4	13	8	7	15	21	6	24
9—11 „	4	6	7	4	14	0	6	9	5
12—14 „	7	(0)	(0)	(25)	(0)	(0)	14	0	15
Over 14 „	2	13	9	3	(0)	11	10	3	18

— means: no positives were found for the species
( ) means: less than ten positives were found for the species

The tendency to produce more gametocytes according as immunity is lower is clear in this table. Before spraying this is apparent in the younger age-groups, after spraying also by an increase of the percentage of gametocyte-carriers among the positives of other age-groups.

In the next table the total of the gametocytes of the three species is expressed for each age-group as a percentage of the total number of blood slides examined, and of the total number of positives found.

Age-groups	Per cent. gametocytes in total number of blood samples			Per cent. gametocytes in positives only		
	before spraying	1955	1956	before spraying	1955	1956
Under 1 year	13.4	1.2	1.4	30.2	(100)	(50)
1 „	29.3	2.7	8.1	35.7	15	60
2 years	30.6	21.0	11.1	38.8	44.7	43.8
3— 5 „	16.8	18.0	17.3	21.4	28.9	46.7
6— 8 „	9.4	3.6	11.5	13.4	7.0	25.0
9—11 „	2.5	4.0	1.9	5.0	11.1	6.3
12—14 „	5.6	0.0	1.3	15.6	0.0	6.0
Over 14 „	1.3	0.7	1.5	4.5	4.8	14.1

( ) means: less than ten positives were found in the age-group

Comparison of this table with Table XXI A shows that the gametocyte-reservoir is not diminished as much as the absolute parasite rate, and in some age-groups even remained at the same level. This is even more marked when one takes into consideration that in the above table, mixed infections with gametocytes are calculated twice or even three times in one positive. And mixed infections occurred most before spraying and least in 1956.

The relation between the extent of gametogenesis and immunity has been generally observed also elsewhere (SCHÜFFNER, 1919; BISHOP, 1955; MORIN, 1955), and is an unpleasant result of the decrease of immunity in the community. On the other hand, from MACDONALD's formula (Chapter I, para. A.j):

$$s = \frac{p^n \, ax}{ax - \log_e p}$$

it will be seen that the influence of the gametocyte reservoir x on the sporozoite rate s is of far less importance than the influence of longevity p, which is raised to the n-th power. The existence of an undiminished gametocyte reservoir therefore compensates only partly the shorter average duration of life of the anopheline population, obtained by residual spraying.

Surveys of infants born after spraying were made regularly (Table X), because they give the first perceptible indication of diminished transmission. In total 280 control infants were born in the villages of the holo-endemic area between the date of first spraying and the date of re-survey in 1956. Of these, forty died, twenty-two of whom had been examined once or more for malaria parasites during previous surveys, but never

found positive. Of the forty deaths, eight had died before or shortly after birth; three of them were with certainty premature. Six other prematures died within one month of birth. This leaves twenty-six other deaths of which, according to the village headmen, three had shown fever and convulsions. In these cases, cerebral malaria cannot be excluded. Of the others, the cause of death was completely unknown in twelve, while in eleven cases other diagnoses than malaria were more or less probable.

In the 1956 survey, 232 control infants born after spraying (age-groups under 2 years in Table XX A) were examined for malaria, of which fourteen were positive. If we apply, for each age-group separately, the percentage of positives found for that age-group before spraying (Table XV), 138 would be positive. A reduction of about 90 per cent. has thus been obtained. Moreover, one of the fourteen positives had probably been infected outside the sprayed area.

It would serve no useful purpose to record the details of all the infant surveys done since the first spraying. The first control infant found positive was 7 months old and infected with *P. vivax*. Of all the surveys performed since spraying until April 1956, a total of twenty-four positive control infants were known in the holo-endemic part of the Lake Area, of whom two had most probably got their infections outside the sprayed area and two had congenital infections. Of the latter, *P. falciparum* was found in one six days after birth, while the second child, according to the parents, fell ill shortly after birth and had fever regularly since. When we first saw it, it was 7 weeks old, and its blood slide contained *P. malariae*. It received a single-dose treatment with nivaquine after which it was found negative on six subsequent occasions during the following twelve months and grew up in perfect health.

The twenty-four positives showed *P. falciparum* ten times, *P. vivax* seven times *P. malariae* three times, mixed infections of *P. falciparum* and *P. vivax* three times, and of all three species, once. Probably three of the children had been infected twice because different species were found with long intervals in between. This makes twenty-three known natural infections in this part of the area. Four of these were found in 1956 in Poeé, eastern Lake Area.

Between April and October 1956 eight more new infections were discovered in the holo-endemic part of the area (Second and Third Quarterly Report 1956, Malaria Division).

2. *Meso-endemic part of Lake Area*

In the meso-endemic part of the Lake Area improvement was practically restricted to the first year after spraying (Table XXI B, Figures V—VII incl.).

The spleen rate in this area behaved practically alike to that of the holo-endemic part, though somewhat more irregular. The same is true for the average spleen sizes.

The A.P.R. and the A.S.I.R. decreased in all age-groups above one year,

but increased again in some groups during the second year. In the age-groups of 2 years and older, and for the first year after spraying, all decreases are significant, apart from that in the 35—44-year group, where the possibility that the difference is due to chance is more than 5 per cent. In the 1-year group this possibility is also more than 5 per cent., and the difference is therefore insignificant.

The number of mixed infections was reduced after two years to approximately the same extent as the number of positives. The divergence between the A.P.R. and the A.S.I.R. thereby remained of the same magnitude. After two years more mixed infections were found than after one year.

The H.I.R. decreased only slightly. Again, this rate was higher two years than one year after spraying. The figures are too small for diagrammatic illustration.

The changes in the ratio of the three species of parasites were as follows:

Survey	Per cent. P. falciparum	Per cent. P. vivax	Per cent. P. malariae
1953, before spraying	50	22	28
1955, one year after spraying	27	38	35
1956, two years after spraying	50	19	31

The restoration of the ratio to the original proportions but at a lower level of endemicity is also apparent in this meso-endemic region. The same applies to the initial fall of *P. falciparum* and relative rise of *P. malariae*. In contrast to what was seen in the holo-endemic part, *P. vivax* showed an initial relative rise in 1955. Only the number of *P. malariae* infections may still diminish somewhat; otherwise the new level seems to have been reached.

The number of gametocytes found for the three species in the various age-groups before and after spraying is given, for the meso-endemic area, in Tables XV B, XIX B, and XX B. The figures are too small to express the number of gametocytes as a percentage for each species. In the following table, the total of the gametocytes of the three species is expressed for each age-group as a percentage of the total number of blood slides examined, and of the total number of positives found.

Age-groups	Per cent. gametocytes in total number of blood samples			Per cent. gametocytes in positives only		
	before spraying	1955	1956	before spraying	1955	1956
Under 1 year	0.0	0.0	0.0	0.0	(0)	(0)
1 „	5.2	4.6	1.0	43.3	(50)	(25)
2 years	6.6	1.3	2.2	29.2	(33)	(50)
3— 5 „	7.6	2.3	4.3	32.4	22.2	46.2
6— 8 „	4.3	2.3	5.1	21.1	21.7	45.2
9—11 „	4.0	2.2	1.6	18.6	23.8	28.2
12—14 „	1.0	3.6	2.0	3.7	(33)	11.8
Over 14 „	1.4	0.6	0.9	10.0	8.7	10.0

( ) means: less than ten positives were found in the age-group

From the figures it may be concluded that in this meso-endemic area, as in the holo-endemic part, the gametocyte reservoir did not diminish as much as the parasite reservoir.

From the infant surveys the following figures are derived. In total, 367 control infants were born in the village of the meso-endemic area between the dates on first spraying and the date of re-survey in 1956. Of these, forty-nine died since, twenty-one of whom had been examined once or more times for malaria parasites during previous surveys. Only one had been found positive for *P. malariae* five days after birth. The child was treated, but died at the age of 2 weeks with symptoms of jaundice, which probably had no relation to the malaria infection. Of the forty-nine deaths nine had died before or shortly after birth; three of them with certainty were premature (two with congenital deformities). Eight other prematures died within one month of birth. This leaves thirty-two, of whom, according to the village headmen, five had shown symptoms of fever. In these cases malaria cannot be excluded. Of the others, the cause of death was completely unknown in eighteen; one had suffered from congenital quartana and jaundice, while in eight cases other diagnoses were more or less probable.

In the 1956 survey, of the 318 control infants still alive, 225 were examined for malaria (age-groups under 2 years in Table XX B), seven of which were positive. When applying the percentages of positives of before spraying, twenty-one would be positive. This means a reduction of about 65 per cent.

Of the controls not investigated in the 1956 survey, many had moved with their families from the islands to new settlements on the shore of the lake. One of these settlements became the new village Waina, which will be treated separately. Apart from the infected children in the latter village, fourteen positive controls were known from the meso-endemic part of the Lake Area as a result of all the surveys since spraying until April 1956. Of these, one was the congenital *P. malariae* infection already mentioned, and another one had been out of the sprayed area. The fourteen positives showed *P. falciparum* eight times, *P. vivax* once, *P. malariae* twice, mixed infections of *P. falciparum* and *P. vivax* once, and of *P. vivax* and *P. malariae* twice.

Between April and October 1956, four more new infections were found in the meso-endemic part of the Lake Area (Second and Third Quarterly Report 1956, Malaria Division).

b. *The Surrounding Area*

The five inland villages in the Surrounding Area were sprayed for the first time in February 1954. In December of that year the first infant control was held, which yielded two positives in twelve infants, one of which had been outside the sprayed area. In September 1955 six positives were found in thirty control infants under 1 year, and eleven positives in fifteen control infants of the 1-year age-group, which makes a total of

seventeen positives in forty-five controls. Several of these positives had been outside the sprayed area, while, moreover, the houses of one of the villages had recently been destroyed by stormwater, after which the inhabitants had lived for some time in unsprayed primitive shelters. Moreover, some families — infants included — had slept in unsprayed shelters in the gardens. For a number of positives, however, no excuse could be found.

After renewed spraying all controls were re-examined for malaria several times. By February 1956, out of fifty-five control infants born since the first spraying, twenty-three (42%) had been found positive on one or more occasions.

In the course of 1954 and 1955 a few new Papuan settlements were established in the plains north of Sentani Lake. This development is an interesting result of changes in the social and economic life of the autochthonous population, which changes are closely bound up with the neighbourhood of Hollandia. Until recently the indigenous economy was a purely subsistence economy and agriculture was practised to provide for the family only. But because good prices are now being paid for fruit and vegetables in the rapidly extending capital of Netherlands New Guinea, the Papuans have an inducement to till more gardens than formerly, and sell their produce in the market. This development is most marked in the area nearest to Hollandia, i.e. in the eastern Lake Area. Groups of families have left the islands and settled near the gardens on the shore. The new settlements are therefore mainly inhabited by semi-immunes, originating from the meso-endemic part of the Lake Area.

In December 1955 the inhabitants of two of these settlements were examined for malaria. One of the two was Waina, along the border of a marsh in the north-eastern corner of the lake; the other one is the Sentani settlement, situated in a better drained plain near Sentani, the administrative centre of the region (see Map). In Waina the people often lived for many months in primitive shelters before the houses were built, and some time would pass before the newly-built houses were sprayed. From this village many cases of malaria had been reported, which gave the impression that malaria had assumed almost epidemic proportions. No such alarming reports were known from the Sentani settlement.

The results of the surveys are tabulated in Tables XXII A and B, from which it will be seen that the various indices in Waina are very high indeed when compared with those of the meso-endemic Lake Area two years after spraying. They even do not differ much from those of the holo-endemic part at that time (Table XX A). The figures of the Sentani settlement are much alike to those of the meso-endemic Lake Area (Table XX B), which is the more striking because some people from Sere, a holo-endemic village, had been included.

Of the twenty infants born in Waina since spraying, eight are known to be infected.

TABLE XXII
SPLEEN- AND PARASITE SURVEY IN NEW SETTLEMENTS, DEC. 1955

Place and date	Age-groups	Number	Spleen rate %	Average spleen	Average enlarged spleen	Absolute par. rate %	All spec. inf. rate %	P. falcip.	P. vivax	P. mal.	Non classif.	Heavy inf. rate %
A. Waina settlement Dec. '55	under 1 year	12	83	1.1	1.3	8	8	1	—	—	—	0
	1- 2 years	13	46	0.9	2.1	23	23	3	—	—	—	15
	3- 8 „	33	82	1.5	1.8	42	45	9	3	3	—	6
	9-14 „	19	95	1.7	1.8	53	58	5	3	3	1	16
	15-24 „	21	71	1.2	1.7	33	38	5	—	3	—	0
	25-34 „	27	81	1.1	1.4	18	18	2	1	2	—	4
	over 34 „	24	78	1.1	1.4	17	17	4	—	—	—	0
	Total	149	76	1.3	1.7	28	31	29	7	11	1	5
B. Sentani settlement Dec. '55	under 1 year	8	63	0.7	1,6	13	13	1	—	—	—	13
	1- 2 years	14	21	0.2	1.0	7	7	1	—	—	—	0
	3- 8 „	17	58	0.8	1.4	18	18	1	1	1	—	6
	9-14 „	—	—	—	—	—	—	—	—	—	—	—
	15-24 „	20	85	1.2	1.4	5	5	1	—	—	—	0
	25-34 „	20	58	0.8	1.4	5	5	—	—	1	—	0
	over 34 „	8	75	1.2	1.7	38	38	2	1	—	—	0
	Total	87	60	0.9	1.4	11	11	6	2	2	—	2

c. *The Nimboran Control Area*

From Tables XVII A and B it will be seen that no substantial changes occurred in the malariometric indices of the inhabitants of the Nimboran Control Area during the time that fair reduction was obtained in the Lake Area.

In July 1955 the Grimé Plain, including the Nimboran Valley, was sprayed with a 1.25% emulsion of dieldrin, prepared from Dieldrex 15, the same formulation as was used in experimental house II (Chapter II), and applied at a rate of 500 mg per square metre. During the first infant survey, in October 1955, no positives were found in twenty-seven babies. However, as Table X shows, rainfall had been far below the average the previous months, and the number of mosquitoes probably as well.

In December 1955 a second infant survey showed rather disappointing results: of forty-three control infants fourteen were positive. Although by pre-spraying standards about twenty-four should have been positive, fourteen is an extremely high figure. Moreover, anophelines could be collected by day in considerable numbers — a total of 122 — from the walls six months after spraying. The latter finding was confirmed in an area near Merauke, in southern New Guinea, where the same formulation had been used.

Fearing that something was wrong with this formulation, it was decided to re-spray the Nimboran and adjacent regions with dieldrin wettable powder, a formulation only recently available on the market in sufficient quantities, and for Netherlands New Guinea provided by UNICEF. In October 1956, an infant survey revealed nine positives in fifty-six control infants born since spraying with wettable powder (VAN DIJK, personal communication). The infections were most probably contracted during sleeping in the garden, a habit which is of some importance in the Nimboran Area. Some mosquitoes could be collected from sprayed walls in the morning. However, because of the little irritating properties of dieldrin, this need not to be alarming, as long as survival tests for delayed mortality are not done.

During the observations in the dieldrin-experimental house, described in Chapter II, it was noticed that the insecticide began to lose much of its potency after the third month of application. Probably this loss of insecticidal power is also the cause of the disappointing results of the infant survey of December 1955.

With DDT abnormal loss of potency could be explained by absorption below the surface (BARLOW & HADAWAY, 1952). Sometimes this absorption was accompanied by enhanced disintegration because of the iron content of the material of the walls (DOWNS et al., 1951), though the same authors also observed reactivation by a rise in the relative humidity (BORDAS et al., 1953). Inactivity of DDT could also be explained by large crystal seize HADAWAY & BARLOW, op cit.).

Whether one or other of these mechanisms could serve as an explanation of the curious observations in our experiments with dieldrin emulsion is completely unknown. Neither staff nor time was available to go into the problem.

E. ENTOMOLOGICAL DATA (BEFORE AND AFTER SPRAYING)

a. *Comparative catches in holo-endemic part of Lake Area and in Control Area*

In 1953 a number of 744 anophelines were collected in Dojo, the holo-endemic lake village, where they were also dissected, and thoracic-juice slides made. The results are summarized in Table V; details are shown in the table on the next page.

The same tendency of a higher sporozoite rate in the indoor catches which was observed in the Nimboran, and is discussed in Chapter I, para. A.k, is seen in this series also. That the difference is not significant may be due to the fact that the night catches were not entirely made in the evening hours, but were sometimes continued after midnight.

In 1954, after the Lake Area was sprayed, five comparative — and mostly simultaneous — catches were held in Dojo and in the Nimboran Control Area. In 1955 and 1956 the catches in Dojo were continued at irregular intervals. In the Nimboran, only on one occasion were dissections

	A. punctulatus	A. farauti	A. koliensis	A. karwari	A. longirostris	Total	Per cent.
Night catches on human baits	4	248	220	87	3	562	
Sporozoite-positive	—	1	2	2	—	5	0.9 ± 0.4
Indoor-daytime catches from walls	—	13	128	41	—	182	
Sporozoite-positive	—	—	2	2	—	4	2.2 ± 1.1
Total:	4	261	348	128	3	744	
Sporozoite-positive	—	1	4	4	—	9	1.2 ± 0.4

done in these years; this time gland dissections. Details of these comparative catches are tabulated in Table XXIII. It should be mentioned that in Dojo never one anopheline was found indoors by day on sprayed walls.

The percentage of sporozoite-positive anophelines in Dojo decreased from 1.2 ± 0.4 before spraying to 0.2 ± 0.1 after spraying. The probability that this diminution is due to chance is less than 5%. When comparing the percentage of positive night catches on human baits after spraying in Dojo, and that in the unsprayed Nimboran, the former is also consider-

TABL

COMPARATIVE MOSQUITO CATCHES IN THE SPRAYE

Date	Dojo village in holo-endemic Lake Area (sprayed)														Night catc
	Night catches on human baits														
	A. punct.		A. far.		A. kol.		A. karw.		A. long.		Total		A. punct.		A. far.		A. k
	No.	+	No.	+	No.	+	No.	+	No.	+	No.	+	No.	+	No.	+	No.
1954																	
5/2 – 9/2													26	—	16	1	17
9/3 –23/3													68	—	50	—	32
31/3 –14/4	4	—	105	1	116	—	163	—	12	—	400	1					
8/6 –22/6	42	—	122	—	323	—	217	—	—	—	704	—	43	—	7	—	9
20/8 – 3/9	1	—	8	—	19	—	10	—	—	—	38	—	189	—	—	—	4
5/11–11/11	10	—	40	—	144	—	13	—	—	—	177	—	30	—	—	—	—
14/12–21/12	5	—	19	—	37	—	2	—	—	—	63	—	58	—	—	—	3
1955																	
22/2 – 7/3	12	—	138	1	102	2	1	—	—	—	253	3					
28/5 –15/7													196	3	93	2	208
16/6 –20/6	20	—	5	—	8	—	—	—	—	—	33	—					
1956																	
9/1 –18/1	7	—	18	—	38	—	—	—	—	—	63	—					
5/3 –17/3	9	—	66	—	45	—	—	—	—	—	120	—					
Total	110	—	521	2	802	2	406	—	12	—	1851	4	610	3	166	3	273
per cent. sporozoites											0.2 ± 0.1						

ably lower than the latter. The after-spraying Dojo catches were sometimes made in the evening hours and sometimes after midnight. Comparison of the results of the total of the pre-spraying catches in Dojo, and of the "whole night" catches in the Nimboran, with the after-spraying catches in Dojo may therefore be justified; and it may be concluded that, while in the Control Area no substantial difference can be observed between the sporozoite rates of anophelines dissected in 1954 and in 1955, a significant decrease was seen in the Lake Area after spraying.

b. *Meso-endemic part of Lake Area*

Before spraying, ten days were devoted to catching mosquitoes in three of the meso-endemic islands, but because of strong winds the only catches that yielded any results were the indoor catches by day, when 159 anophelines were collected from the walls. Most were collected on Jobe, the island nearest the shore, fewest on Poejo I, farthest from the breeding places. Details are as follows:

	Jobe	Ifar	Poejo I	Total
A. punctulatus	4	5	—	9
A. farauti	9	4	—	13
A. koliensis	88	17	32	137
Total	101	26	32	169

The Jobe mosquitoes only were dissected, and all were found negative.

II
E AREA AND UNSPRAYED CONTROL AREA.

Holo-endemic Nimboran Control Area (unpsrayed)																			
uman baits					Indoor catches from walls												Total general Contr. Area		
arw.	A. long.		Total		A. punct.		A. far.		A. kol.		A. karw.		A. long.		Total				
+	No.	+	No.	+	No.	+	No.	+	No.	+	No.	+	No.	+	No.	+	No.	+	
—	—	—	61	1	37	1	14	1	28	—	8	—	—	—	87	2	148	3	
—	2	—	152	—	179	1	53	—	34	1	—	—	—	—	266	2	418	2	
—	—	—	59	—	247	2	25	—	26	—	—	—	—	—	298	2	357	2	
—	—	—	193	—	692	7	—	—	4	—	—	—	—	—	696	7	889	7	
—	—	—	30	—	333	6	6	—	19	—	3	—	—	—	361	6	391	6	
—	—	—	61	—	255	7	1	—	40	—	—	—	—	—	296	7	357	7	
—	3	—	500	8	90	1	32	1	57	—	—	—	—	—	179	2	679	10	
—	5	—	1056	9	1833	25	131	2	208	1	11	—	—	—	2183	28	3239	37	
			0.9 ± 0.3												1.3 ± 0.1		1.1 ± 0.2		

c. *Nimboran Control Area*

Between 28 January and 16 July 1955, large-scale anopheline catches were held in the Nimboran Valley. Some details of these collections have already been discussed in previous chapters and paragraphs. The main object was to obtain an insight in the number of anopheline bites, — especially the bites of sporozoite-positive anophelines —, to which inhabitants of the area are exposed per year.

In areas where the anophelines are distinctly endophylic this number can be calculated by relating the number of sporozoite-positives collected in the morning from the inner walls of rooms to the number of persons which had slept in these rooms (DAVEY & GORDON, 1933). This method cannot be used for exophylic anophelines and it was therefore decided

TABLE XXIV

NUMBER OF ANOPHELINES, COLLECTED IN THE NIMBORAN PER WEEK PER TWO HUMAN BAITS BETWEEN 28 JANUARY AND 16 JULY 1955

Calendar week	Date	Number of catch-nights	Number of anoph. bites	Average per night per 2 men
4	23/1 — 29/1	1	101	101
5	30/1 — 5/2	5	195	39
6	6/2 — 12/2	3	148	49
7	13/2 — 19/2	–	—	—
8	20/2 — 26/2	–	—	—
9	27/2 — 5/3	2	480	240
10	6/3 — 12/3	6	899	150
11	13/3 — 19/3	1	223	223
12	20/3 — 26/3	–	—	—
13	27/3 — 2/4	6	903	151
14	3/4 — 9/4	3	475	158
15	10/4 — 16/4	–	—	—
16	17/4 — 23/4	6	597	100
17	24/4 — 30/4	5	552	110
18	1/5 — 7/5	1	126	126
19	8/5 — 14/5	2	113	56
20	15/5 — 21/5	4	115	29
21	22/5 — 28/5	3	145	48
22	29/5 — 4/6	4	100	25
23	5/6 — 11/6	6	186	31
24	12/6 — 18/6	4	37	9
25	19/6 — 25/6	3	33	11
26	26/6 — 2/7	5	48	10
27	3/7 — 9/7	6	30	5
28	10/7 — 16/7	5	48	10
	Total	81	5554	68.5

to try to obtain an insight in the order of magnitude of the figure by direct observation. A number of 81 "whole night" catches, particulars of which have been described in Chapter I, para. A.c, were organised. Unfortunately, on nights of extremely high mosquito prevalence not all anophelines that bit could be caught. The actual catches are summarized in Table XXIV, from which it can be concluded that on an average the human baits were bitten by more than 34 anophelines per man per night. In Figure VIII the catches are correlated to the rainfall at the time of the observations. The unit of time is one week. The white columns represent the averages in millimetres of the amounts of rain per week, registered by four rain meters set at different places in the valley; the black columns the average number of mosquito bites per person per night for the week in question. The rain figures differ somewhat from those in Table X, because in that

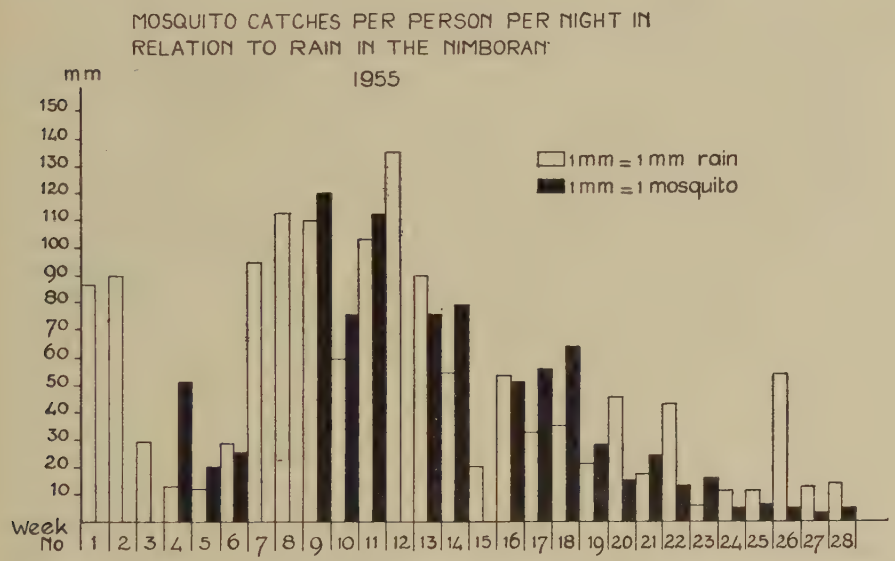


FIG. VIII.

table only the figures for Genjem are recorded. From that table it may be seen that about 220 mm of rain is the monthly average, and that usually five wet months are above, against seven relatively dry months below, this average (5 : 7). A glance at Figure VIII makes it clear that for 1955 the line between the wet and dry seasons can be drawn after the 15th calendar week. It appears, then, from Table XXIV that 27 catch-nights with an average of 64 anophelines per person per night felt in the wet season, against 54 catch-nights, with an average of 20 anophelines, in the dry season (1 : 2). When, therefore, the average of 34 anopheline bites per person per night, calculated from the 81 catch-nights, is put as an average of value the whole year round, this figure is certainly not too

high. It implies that an adult Papuan inhabitant of the Nimboran Valley is bitten by about 12,500 anophelines per year.

The analysis of the mosquitoes collected during this series of catches is as follows:

A. punctulatus	A.farauti	A. koliensis	A. longirostris	Total
2506	684	2364	14	5568

Gland dissections could be performed on only 500 of these anophelines, i.e. on those collected between 28 May and 15 July 1955. Sporozoites were found in eight, or 1.6% ± 0.6% (Table XXIII). Of the 1954 catches 1.1% ± 0.2% had been found positive. A percentage of positives of between 1.0 and 1.5 therefore seems a good estimate, which implies that the adult Nimboran Papuan is infected with malaria about 150 times per year. In view of the safety margins observed for the calculations, this figure may be even higher and approach 200.

As will be seen from Figure VIII, the abundance of anophelines is closely related to rainfall. When the latter is low, the former also diminishes very soon. This is another indication of the short longevity of anophelines of the *punctulatus* group.

What strikes one is the high number of *A. punctulatus*, compared with other species of the group found in the Nimboran in 1954. Because *A. punctulatus* prefers temporary breeding places, it was thought that human activities in connection with the community development project, going on in the vicinity of Genjem, might be responsible for abnormal breeding of this species. A number of breeding places were found, indeed, in places where trees had been felled along the new airfield which was made without any foreknowledge on the part of the malariologist. Breeding places were also found in wheelruts on the road. However, mosquito catches in villages miles away from airfield and road revealed a predominance of *A. punctulatus* there also. Moreover, the malariometric indices of these villages were equal to those near Genjem. It may therefore be concluded that, though some more breeding may have taken place temporarily, this has not influenced the degree of endemicity of the area.

In 1955 the breeding places near the airfield were overgrown again. But this alone cannot be held responsible for the fact that in that year *A. koliensis* came to the fore. Probably climatological factors are responsible for this change in the relative prevalence of anophelines of the *punctulatus* group. At times such a change could be observed in other regions of New Guinea as well.

F. Discussion of the malariometric results

Relatively to the pre-spraying conditions the best results with DDT spraying were observed in the holo-endemic part of the Lake Area. The parasite load of the community living in that part diminished considerably, and infections in infants became very scarce. But, though a further decrease

in the absolute parasite rate in some age-groups may be anticipated, transmission was not completely interrupted, and eradication of the disease will therefore not be achieved by prolonged residual spraying with DDT. The restoration of the original ratio of the three species of parasites indicates that the new and lower level of endemicity is almost approached.

Lowering of the endemic level by DDT will result in changes of immunity of the community against malaria infections. Assuming that spraying with this insecticide were continued, it might be expected that for several years to come the curve, representing the course of the absolute parasite rate through the various age-groups, would alter, before its definite shape is attained.

The finding of a few sporozoite-positive anophelines also points to continued transmission.

In Poeé, one of the two eastern holo-endemic lake villages, improvement was less marked. Of the twenty-four known infections in infants in the entire holo-endemic lake area, four were found in this village during the last survey, while the absolute parasite rate showed no improvement since the 1955 survey, and was above the average of the area. It is not impossible that the changes in the people's socio-economic life, observed in the eastern Lake Area and discussed in a previous paragraph, are responsible for these facts. This development not only induces the population to settle on the shore, but causes them to spend nights in the gardens to avoid time-wasting travel. While at the start of the experiment this custom was practically non-existant, during the 1956 survey it was admitted several times that a feverish child had slept in the gardens.

This new custom may also be responsible for the fact that during the second year of observations not much improvement was achieved in the meso-endemic Lake Area. The new level of endemicity seems to have been reached here. At first sight it may seem surprising that malaria could not be eradicated by DDT indoor-spraying in a region where malariometric indices point to meso-endemicity. However, when one considers that, in fact, the whole Lake Area is holo-endemic, but that some inhabitants avoid a number of infections when spending the nights on small islands without transmission, it will be clear that success in the meso-endemic part greatly depends on success in the holo-endemic part. It is the same as with persons regularly using a mosquito net in a malarious region where other people do not: as soon as the mosquito net is neglected, they are exposed to the same risks as the other people.

Also in the Surrounding Area success was influenced by factors which prevented the population to make full use of the protection offered by DDT-sprayed houses. In Waina people lived in primitive shelters while building a new village. In one of the inland villages the same circumstances prevailed for some time after the village had been destroyed by storm-water. Moreover, in these villages the custom of sleeping in the gardens is of some importance. All this made that success was less marked here

than in the holo-endemic Lake Area, and in the new Sentani settlement.

From the experiment in the Lake Area it may be concluded after two years of observations since DDT was first applied, that

1) an on the whole considerable and highly significant reduction was obtained in the malariometric indices, and particularly of the absolute parasite rate, the all species infection rate and the heavy infection rate;

2) a significant reduction in the sporozoite rate of the vector-anophelines was noticeable;

3) eradication of malaria, exclusively by DDT-indoor spraying, was not achieved, and cannot be anticipated.

In the Nimboran Valley, the period of observations, since spraying with dieldrin started, was too short for definite conclusions. However, the results of the infant surveys and entomological observations performed since dieldrin wettable powder was applied, warrant the supposition that transmission in the villages has been interrupted, but that foci of transmission are maintained in gardens and sago-marshes.

These conclusions agree completely with the expectations expressed in Chapter II, on the ground of the results obtained in experimental houses, and of the results of entomological observations.

CHAPTER IV

OBSERVATIONS OTHER THAN STRICTLY MALARIOMETRIC IN THE LAKE- AND CONTROL AREAS

"The success of control schemes must be measured by their effect on the health of the population, and not by the lowering of the easily measured malariometric indices" (COLBOURNE & WRIGHT, 1955). This line of thought underlies the investigations which will be recorded in this chapter. They concern the evaluation of the possible effects of malaria control, however incomplete, on the trend of the population and on the weight and height of children.

From the Tables XI A and XI B it will be seen that the villages of the meso-endemic part of the Lake Area have, as a rule, more inhabitants than of the holo-endemic part. Dojo, showing the highest figure of the latter part, consists in fact of four small villages. Since, as far as is known, other conditions and possibilities for the two areas are practically the same, it is not unlikely that malaria has played its part as a cause of this uneven distribution of population, though we do not know whether in former times mutual wars may locally have caused depopulation.

Other aspects of human life in the meso-endemic area also compared favourably with those of the other part. On the whole the houses in the former are better built and better kept. It gives one the impression that the population of the meso-endemic part are somewhat more energetic and show a little more initiative. For example, in January 1955, of the approximately 4300 inhabitants of the meso-endemic part, 144 (94 boys and 50 girls) attended a school or a training course outside the area, against only 44 (30 boys and 14 girls) of the 2450 inhabitants of the holo-endemic part.

Birth- and death-rates of the years before 1954 are not known. For 1954 and 1955 accurate records were kept of births and deaths. For the determination of the causes of death the main source to be relied on was information obtained from village headmen or schoolteachers, but sometimes hospital diagnoses were available. Birth- and death-rates are tabulated in Table XXV.

In the holo-endemic Lake Area the improvement in the birth- and death-rates, compared with 1955, is significant; in the meso-endemic Lake Area it is not.

The ages of the cases of death for the two years of observation are tabulated in Table XXVI. It is seen that in 1954, excluding still births, about 35 per cent. of the cases of death in both parts of the Lake Area

TABLE XXV

TREND OF POPULATION IN LAKE AREA

Area	1954						1955					
	Births		Deaths		Increase		Births		Deaths		Increase	
	No.	‰	No.	‰	No.	‰	No.	‰	No.	‰	No.	‰
Holo-endemic Lake Area	110	45 ± 4	91	37 ± 4	19	8	161	66 ± 5	57	23 ± 3	104	43
Meso-endemic Lake Area	194	46 ± 3	94	22 ± 2	100	24	234	54±3.5	82	19 ± 2	152	35
Total Lake Area	304	46 ± 3	185	28 ± 2	119	18	395	59 ± 3	139	21 ± 2	256	38

involved infants, and almost 60 per cent. children under 10 years. Over 10 years the population gradually decreases. Deaths in which senescence may play a part are therefore relatively scarce.

The figures for 1955 show that infants and children contributed most to the lowering of the general death rate for that year. This improvement of the death rate, added to a high birth rate in 1955, resulted in a striking increase of the population.

Premature birth was the cause of infantile death several times, viz. eight times in 1954 and four times in 1955. Of the total, eight were twins. It is not likely therefore that malaria was a frequent cause of premature birth. Malaria was not diagnosed as a direct cause of death.

It is difficult to comment on the figures of the Tables XXV and XXVI because there are no possibilities for comparison with pre-spraying figures form the Lake Area. Certainly, the figures for 1955 are good by New Guinea standards, and better than for 1954. But we do not know whether 1954 must be classified as "normal", or also as "good". That 1954 and 1955 were probably both "good" years may, however, be indicated by the spontaneously expressed opinion of village headmen and schoolteachers that, within their memory, there had never been so many children in the villages. This may be accidental, but it is more likely that it is the result of the joined efforts of the Division for Mother and Child Health, the Division for Yaws Control, and the Division for Malaria Control. With regard to the latter, its influence may be detected in the relatively greater improvement observed in the holo-endemic, as compared to the meso-endemic, part of the Lake Area. Already from the bigger size and the better appearance of the villages in the meso-endemic part before spraying, it could be concluded that in several respects they were better off than the highly malarious villages. The difference in the death rates of 1954 in the two parts still supported this assumption, while in 1955 no significant difference could be observed between these rates. The yaws

TABLE XXVI
AGES OF CASES OF DEATH DURING TWO YEARS OF OBSERVATION IN THE SENTANI LAKE AREA

Age	Holo-endemic Sentani				Meso-endemic Sentani				Total			
	1954		1955		1954		1955		1954		1955	
	No.	Per cent.	No.	Per cent.	No.	Per cent.	No.	Per cent.	No.	Per cent.	No.	Per cent.
Still births	4	4	2	4	0	0	8	10	4	2	10	7
Live births :												
1st week	–	–	1	2	7	7	2	2	7	4	3	2
1st month (total)	6	7	8	14	12	13	5	6	18	10	13	9
1st half-year (total)	19	21	13	23	27	29	14	17	46	25	27	19
under 1 year (total)	32	35	17	30	32	34	18	22	64	35	35	25
1 year	14	16	3	5	6	6	6	7	20	11	9	6
2–4 years	5	5	4	7	11	12	3	4	16	9	7	5
under 5 years (total)	51	56	24	42	49	52	27	33	100	54	51	37
5–9 years	3	3	5	9	6	6	9	11	9	5	14	10
under 10 years (total)	54	59	29	51	55	59	36	44	109	59	65	47
11–50 years	28	31	20	35	28	29	24	29	56	30	44	32
over 50 years	5	6	6	10	11	12	14	17	16	9	20	14
Total cases of death :	91	100	57	100	94	100	82	100	185	100	139	100

control campaign was launched in both areas in 1955; the Division for Mother and Child Health has been active since 1955 in the meso-endemic villages only. The activities of these two divisions cannot therefore have had any influence on the levelling of the difference. Assuming that prolonged obervations will show that the improvement is genuine, it is not unlikely that it is partly due to the abatement of malaria in the Lake Area. At present it is better to forgo further conclusions.

Before and since spraying a great number of weighings and measurements of height were done on infants and children of the Lake and Control Areas. For these weighings and measurements children were selected whose birth dates were known from the books of the Mission, or whose birth dates had been registered by staff members of the Malaria Division.

Before spraying, weighings and measurements were made of infants and children from the holo- and meso-endemic parts of the Lake Area and of the Nimboran Control Area. Some of the Nimboran children under three years were weighed and measured twice, with an interval of six months, while, moreover, a number of 578 weighings were added to our series, involving fifty-one children under 2 years, who in the preceding year had attended the infant welfare clinic. Otherwise it would have been impossible to obtain enough and sufficiently large figures for comparison.

In the Lake Area, the control infants born since spraying were weighed and measured regularly. Two years after spraying this was done not only on these infants but on all children of known age.

Of all the series, prematures were excluded for the first few months. When they were still alive after four or five months they were included at that age. From the series of infants born since spraying, those which contracted malaria were excluded. Otherwise no infant was excluded.

Through lack of sufficient numbers, boys and girls are not dealt with separately, while already after the age of 6 months, 3-months periods had to be used for the subdivisions. The results are tabulated in Tables XXVII and XXVIII, and illustrated graphically in Figures IX—XIV incl.

If malaria has an influence on the weight and height of children, one may expect that this influence will be most noticeable in the age-groups

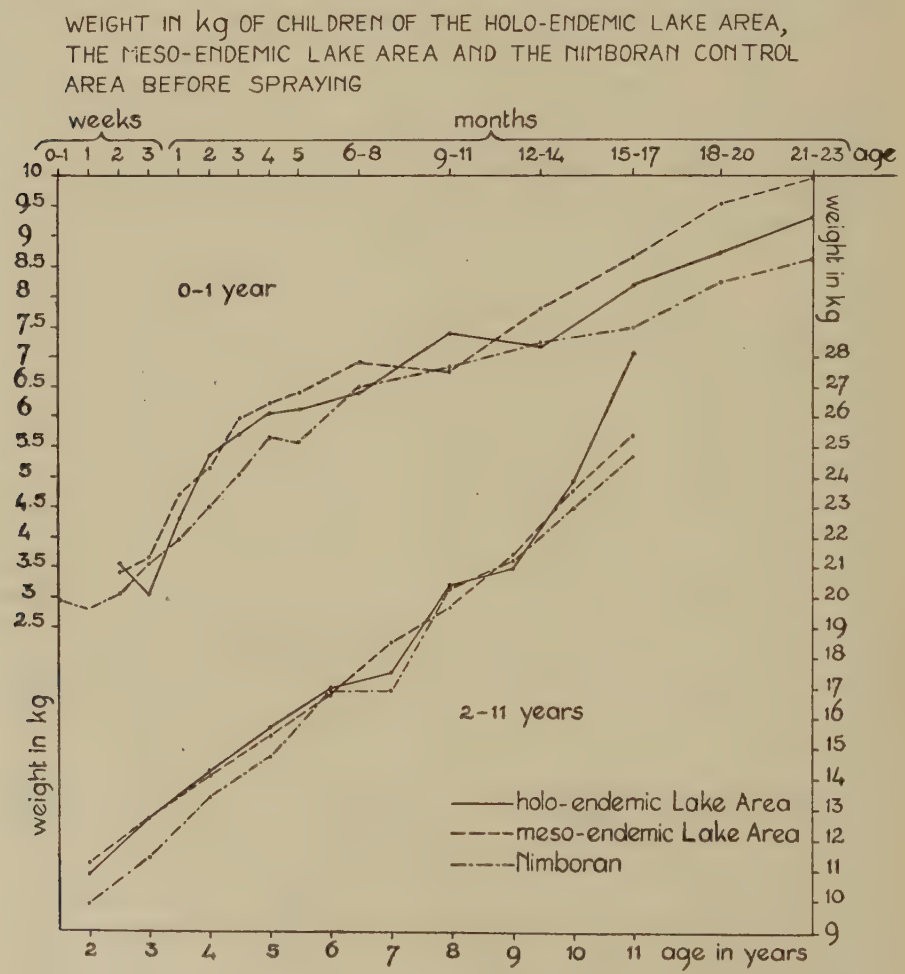

WEIGHT IN kg OF CHILDREN OF THE HOLO-ENDEMIC LAKE AREA, THE MESO-ENDEMIC LAKE AREA AND THE NIMBORAN CONTROL AREA BEFORE SPRAYING
weeks
months
0-1 1 2 3 1 2 3 4 5 6-8 9-11 12-14 15-17 18-20 21-23 age
0-1 year
2-11 years
weight in kg
age in years
holo-endemic Lake Area
meso-endemic Lake Area
Nimboran

FIG. IX.

where the parasite load is heaviest. This is in holo-endemic areas from about 9 months to 3 years (Tables XV A, XVI and XVIII), and in meso-endemic areas from about 2 till 8 years (Table XV B). These tendencies are certainly observable in the diagrams.

With regard to weight, it is seen in Figure IX that, before spraying, this is practically constantly lower in the holo-endemic Nimboran than in both parts of the Lake Area. Differences in nutrition, discussed in Chapter III, para. A.g, may be responsible for this fact. The divergence is greatest at the age that the parasite load is heaviest, which may point to the possibility that the latter is more easily tolerated according as the state of nutrition is better.

At first, the curves of the meso-endemic- and of the holo-endemic part of the Lake Area cross each other constantly. Definite divergence of the two curves starts at the age of about 1 year, when that of the holo-endemic part bends more than that of the meso-endemic part. At that age, children of the holo-endemic part suffer most from their parasite load. Later on the reverse happens, so that, from the age of 3 years onwards, the curves touch again. At this age, the parasite rate in the meso-endemic part is at its peak, while in the holo-endemic part the parasite load has passed its

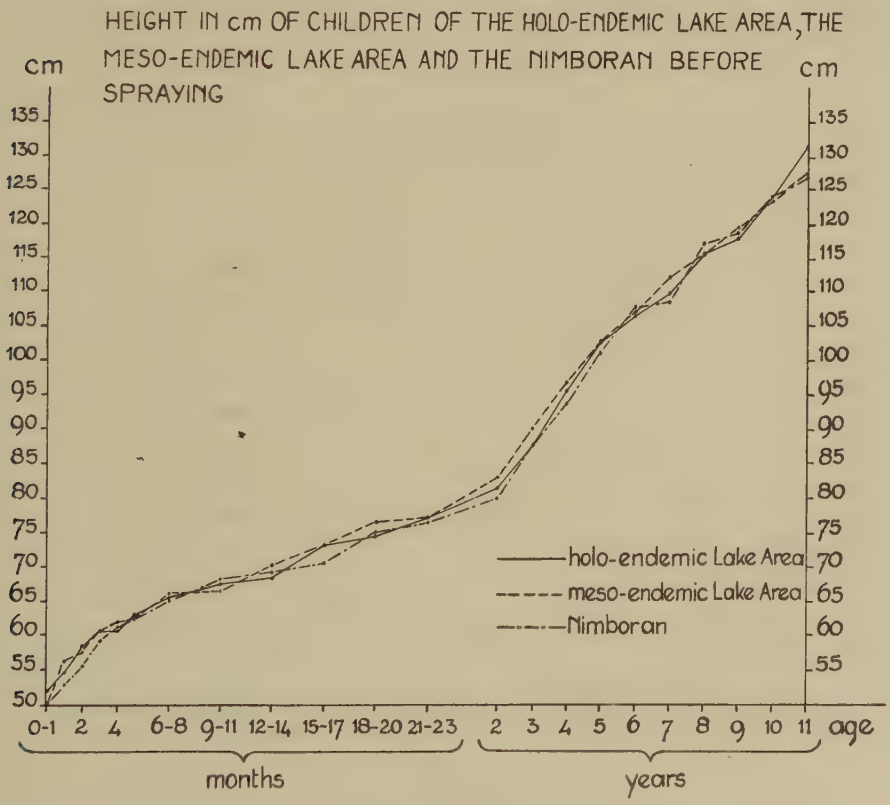


FIG. X.

TABLE XXVII

AVERAGE WEIGHT AND HEIGHT OF INFANTS AND CHILDREN BEFORE AND AFTER SPRAYING

Age-groups	WEIGHT												HEIGHT									
	Holo-endemic Sentani Area				Meso-endemic Sentani Area				Sentani infants		Nimboran		Holo-endemic Sentani Area				Meso-endemic Sentani Area				Sentani infants		Nimboran	
	Before		2 years after		Before		2 years after		Contr. infants free of malaria		Before		Before		2 years after		Before		2 years after		Contr. infants free of malaria		Before	
	No.	Grams	No.	Grams	No.	Grams	No.	Grams	No. of weighings	Grams	No.	Grams	No.	cm.	No.	cm.	No.	cm.	No.	cm.	No. of measurements	cm.	No.	cm.
0- 1 week	—	—	—	—	—	—	2	2.700	9	2.800	4	2.950	—	—	—	—	—	—	2	45.5	9	47.5	—	—
1 „	—	—	5	3.150	—	—	—	—	36	3.150	7	2.850	—	—	5	50.0	—	—	—	—	36	50.0	1	46.0
2 weeks	2	3.550	2	3.400	1	3.400	2	3.950	53	3.300	13	3.050	2	53.5	2	51.5	1	48.5	2	51.5	53	50.0	3	50.5
3 „	5	3.050	9	3.900	1	3.650	1	3.500	57	3.800	18	3.550	5	51.0	9	51.5	1	52.0	1	51.0	57	52.0	4	50.0
1 month	5	4.300	15	4.450	13	4.700	11	4.700	146	4.300	64	3.950	5	54.5	15	55.0	13	56.0	11	55.0	146	53.5	15	53.0
2 mnths.	13	5.350	11	5.100	9	5.150	11	5.150	153	5.150	67	4.500	13	58.0	11	57.0	9	57.5	11	56.0	153	57.0	13	55.5
3 „	12	5.750	8	5.800	8	5.950	9	5.900	156	5.750	67	5.050	12	60.5	8	60.0	8	60.5	9	60.0	156	59.5	10	59.0
4 „	10	6.050	12	6.500	13	6.200	8	5.900	132	6.300	54	5.650	10	60.5	12	62.0	13	61.5	8	60.5	132	62.0	8	61.0
5 „	9	6.100	11	6.750	13	6.400	13	6.900	132	6.650	47	5.600	9	63.0	11	63.5	13	62.5	13	63.5	132	63.5	10	60.5
6- 8 „	16	6.400	48	7.100	32	6.900	29	7.250	351	7.050	105	6.500	16	65.5	48	66.0	32	66.0	29	66.0	351	66.0	28	65.0
9-11 „	18	7.400	23	7.650	33	6.800	40	7.350	299	7.350	126	6.850	18	67.5	23	70.0	33	66.5	40	68.5	299	68.5	33	68.0
12-14 „	29	7.200	25	7.900	33	7.800	29	8.050	198	7.800	100	7.250	29	68.5	25	72.0	33	70.0	29	72.0	198	71.0	25	69.0
15-17 „	24	8.200	15	8.850	41	8.650	26	8.550	107	8.450	70	7.500	24	73.0	15	74.5	41	73.0	26	74.0	107	73.0	23	70.5
18-20 „	29	8.750	18	9.200	25	9.550	17	9.050	54	9.050	44	8.250	29	74.5	18	76.0	25	76.5	17	76.5	54	75.5	23	75.0
21-23 „	28	9.300	21	9.450	41	9.950	23	9.400	35	9.300	24	8.650	28	77.0	21	77.5	41	77.0	23	78.5	35	78.0	18	76.5
2 years	63	10.800	61	11.000	104	11.200	80	10.800			66	9.800	63	81.5	61	83.5	104	83.0	80	83.5			66	80.0
3 „	31	12.700	82	13.100	81	12.700	98	12.600			51	11.400	31	87.5	82	91.0	81	90.0	98	90.5			51	87.5
4 „	53	14.200	52	14.200	68	14.100	77	14.200			24	13.400	53	95.5	52	96.5	68	96.5	77	96.5			24	93.5
5 „	47	15.700	31	15.800	56	15.400	58	15.800			13	14.700	47	102.5	31	102.5	56	102.5	58	103.0			13	101 0
6 „	42	17.000	42	17.300	57	16.800	49	17.200			20	16.900	42	106.5	42	106.5	57	107.0	49	107.5			20	107.5
7 „	39	17.500	46	18.800	62	18.500	48	18.400			14	16.900	39	109.5	46	112.5	62	112.0	48	112.0			14	108 5
8 „	24	20.400	35	20.200	40	19.700	48	20.300			10	20.300	24	115.5	35	114.5	40	115.5	48	116.5			10	117.0
9 „	19	21.000	30	21.800	24	21.400	47	22.200			11	21.200	19	118.0	30	119.5	24	119.5	47	120.0			11	118.5
10 „	16	23.900	26	24.400	20	23.600	22	24.200			8	23.000	16	124.0	26	123.5	20	123.5	22	124.5			8	124.0
11 „	19	28.100	20	26.700	16	25.400	12	26.600			7	24.700	18	131.5	20	128.0	16	127.5	12	128.5			7	127.0

maximum. From the age of 3 years, the curves cross constantly. The high rise of the holo-endemic curve at the age of 11 years is most probably due to chance.

The differences between the holo-endemic part of the Lake Area and the holo-endemic Nimboran are significant in the age-groups 15—17 months, 2 years, 3 years and 5 years (in the 15—17 months, 2- and 3 years groups the probability that the difference is due to chance is less than 0.3 per cent.; in the other group less than 5 per cent. Between the two parts of the Lake Area the differences are significant in the age-groups 18—20 months and 21—23 months (5 per cent. level), and between the meso-endemic part of the Lake Area and the holo-endemic Nimboran, in the age-groups 15—17 months, 18—20 months, 21—23 months, 2 years and 3 years (all 0.3 per cent. level). Above the age of 6 years the three curves cross constantly, significance of differences has not, therefore, been calculated. I may just mention that the curve of the Nimboran, as a rule, remains lowest.

Human height is less influenced by adverse conditions than weight. The height of 50 Nimboran men and 50 Nimboran women, compared with equal members of Sentani men and women, showed practically no differences (Chapter III, para. A.g). Nevertheless the height curves of Figure X show much the same tendency as the weight curves of Figure IX. Between 12—14 months and 5 years, the curve of the Nimboran is usually lowest, and that of the meso-endemic part of the Lake Area highest. Under and above these ages, the curves cross constantly; between these ages, the differences in height between the holo-endemic part of the Lake Area and holo-endemic Nimboran are significant in the age-groups of 15—17 months and 2 years (5 per cent. level); between the two parts of the Lake Area in the age-groups 18—20 months, 2 years and 3 years (5 per cent. level); and between the meso-endemic part of the Lake Area and holo-endemic Nimboran in the age-groups of 15—17 months, 2 years, 3 years and 4 years (0.3 per cent. level for the 2 years group, 5 per cent. level for the other groups).

It gives one the impression that between 1 and 5 years growth is retarded somewhat in the holo-endemic areas, but that, as soon as the parasite load diminishes, the arrears are made up again.

It is certainly not proved that the differences in weight and height, observed between the three regions, are exclusively due to malaria. As already stated, the poorer nutrition in the Nimboran Valley may be of influence with regard to the lower figures for this region. But that the differences occur practically constantly, and are most marked in the age-groups in which they might be expected for malariometric reasons, and that, moreover, in some of these age-groups the differences are significant may give strong support to the supposition that there is a causal relation between malaria and the said differences.

Attention is drawn to a flattening (different from that discussed) in the

weight curves of all three regions after the age of about 6 months. Such a flattening is commonly observed also in African babies. According to JELLIFE & ONWUMERE (1953), malaria is not the main factor interfering with growth at that age. Partial or complete substitution of breast feeding may be responsible for it. The observation that it is present in the holo- and meso-endemic areas in about the same age-groups gives support to this assumption.

In Figures XI and XII, weight and height of children in the holo-endemic part of the Lake Area before spraying are compared with weight and height two years after insecticide application. The after-spraying weight curve is almost constantly higher than the pre-spraying curve. The differences are significant in the age-groups 12—14 months and 15—17 months (5 per cent. level), but in view of the figures of the malaria-free infants shown in Table XXVII it is not sure how much importance should

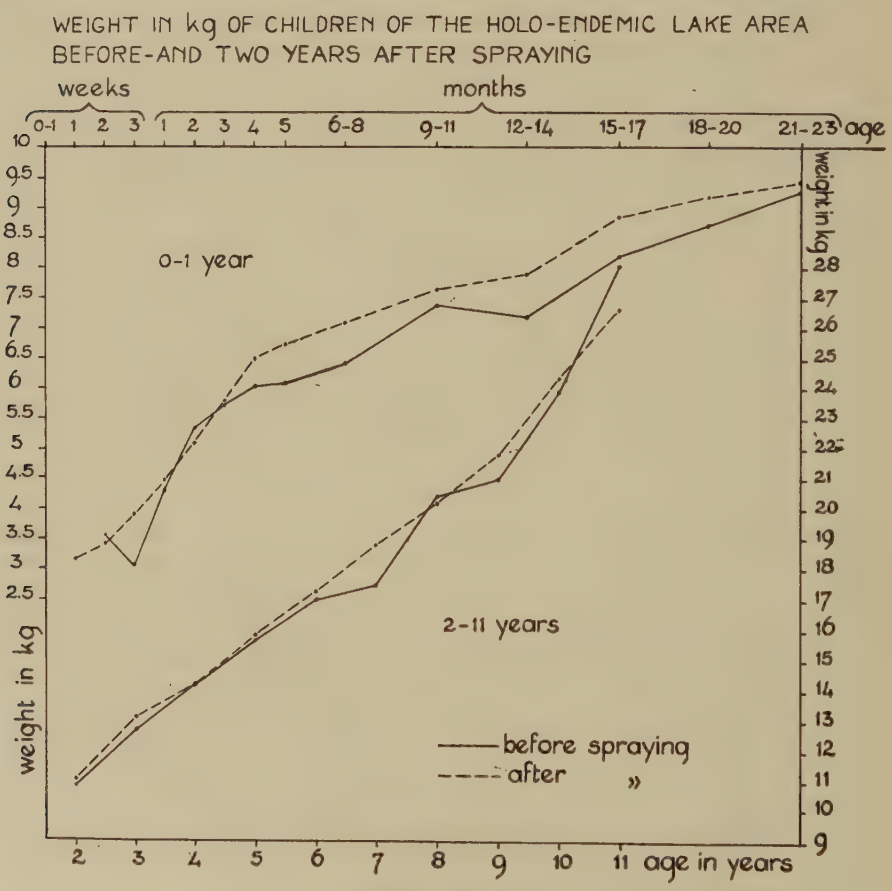

WEIGHT IN kg OF CHILDREN OF THE HOLO-ENDEMIC LAKE AREA
BEFORE-AND TWO YEARS AFTER SPRAYING
weeks
months
0-1 1 2 3 1 2 3 4 5 6-8 9-11 12-14 15-17 18-20 21-23 age
0-1 year
2-11 years
before spraying
after »
weight in kg
weight in kg
age in years

FIG. XI.

be attached to this significance. That, on the other hand, differences would be most marked in these groups, is in conformity with expectations, because in these groups the parasite load was heaviest before spraying. The constancy of the higher level after spraying is also important.

The same considerations are applicable to the after-spraying height curve, which, too, is almost constantly higher than the pre-spraying curve. The differences are significant in the age-groups 9—11 months, 12—14 months, 2 years and 3 years (5 per cent. level in the 2 years group; 0.3 per cent. level in the other groups).

The weight curves in Figure XIII, showing the weights of children in the meso-endemic Lake Area before and two years after spraying, follow an unexpected course. In the age-group 9—11 months, the average weight after spraying is significantly higher (5 per cent. level) than that before spraying, but in the group of 21—23 months it is significantly (5 per cent. level) lower! Later on the differences are never very marked. It may therefore be concluded that in the meso-endemic Lake Area, abatement of malaria had no remarkable influence on weight.

The same conclusion holds good for height. The differences are so small that they could not well be demonstrated diagrammatically. How-

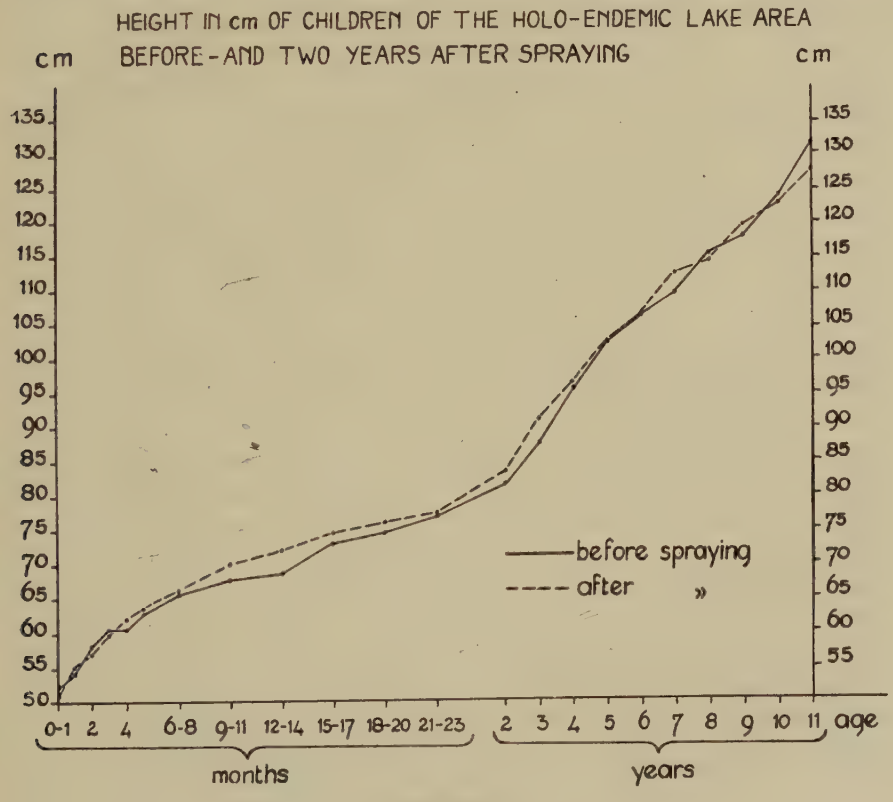


FIG. XII.

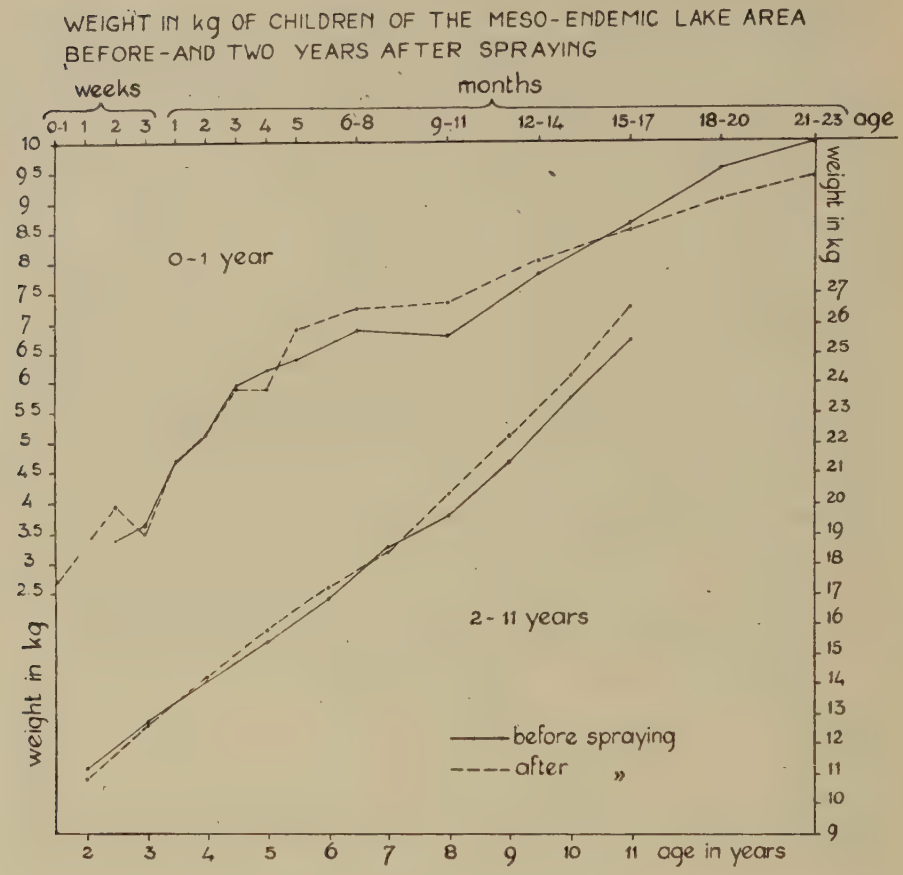

WEIGHT IN kg OF CHILDREN OF THE MESO-ENDEMIC LAKE AREA
BEFORE-AND TWO YEARS AFTER SPRAYING
weeks
months
0-1 1 2 3 1 2 3 4 5 6-8 9-11 12-14 15-17 18-20 21-23 age
0-1 year
2-11 years
before spraying
after »
weight in kg
weight in kg
2 3 4 5 6 7 8 9 10 11 age in years

FIG. XIII.

ever, on the whole the after-spraying figures are higher than the pre-spraying figures (Table XXVII).

The conclusion that in the meso-endemic part of the Lake Area no measurable improvement in weight and height by malaria control could be observed, does not imply that it is proven beyond doubt that the increases found in the holo-endemic part are the result of an abatement of this disease. To furnish proof of this assumption will be almost impossible with the small available material and after two years of observation. Neither the improvement in the vital statistics, nor the differences in weight and height discussed in the present chapter, are in themselves a sufficient yard-stick for the success of malaria control. However, the fact that improvement of the malariometric indices by DDT indoor spraying was accompanied by improvement of vital statistics, as well as by a higher level of weight- and height curves of the children living in the holo-endemic part of the Lake Area, may serve as a strong indication that

abatement of malaria resulted in improvement of the health of the population.

Between the first spraying and the 1956 survey, 647 children were born in the Lake Area, of which forty-six died before they had been examined by staff members of the Malaria Division. A number was not seen because the family removed to the new settlements on the lake shore or to Hollandia, so that about 550 infants remain, who were weighed and measured on one or more occasions during the control-infant surveys. Once a control infant had been found infected with malaria it was omitted from the series. A total of 1918 weighings and measurements were performed on these 550 malaria-free children. For the sake of comparison the results are tabulated in Table XXVII in the same age-groups as the others. Because series of weights and heights of malaria-free children is possibly unique for the lowlands of New Guinea, they are tabulated once more in Table XXVIII, this time for the first fifteen months in weeks- and months-groups, while it is diagrammatically illustrated in Figure XIV. The curves are somewhat smoothed in this figure. For comparison, curves of European children are added (MITCHELL-NELSON, 1946). No differentiation is made between children born in the holo- and those born in the meso-endemic part, because the figures did not justify such differentiation.

The flattening of the weight curve after the age of 6 months, which was discussed in a previous paragraph, is also apparent for these malaria-free children. This supports the opinion of JELLIFE & ONWUMERE (op. cit.).

The weighings and measurements of children under 2 years, done in 1956, two years after spraying (Table XXVII), in so far as these children had never been found infected with malaria, are included in the total. When comparing this total with these separate series of two years after spraying, it appears that the figures of the former are often lower than

TABLE XXVIII

AVERAGES OF 1918 WEIGHINGS AND MEASUREMENTS ON 550 MALARIA-FREE CHILDREN UNDER TWO YEARS BORN IN THE LAKE AREA AFTER SPRAYING

Age-groups	Number of measure-ments	Average weight (grams)	Average height (cm.)	Age-groups	Number of measure-ments	Average weight (grams)	Average height (cm.)
0–1 week	9	2,800	47.5	8 months	104	7,250	67.0
1 week	36	3,150	50.0	9 —	110	7,250	67.5
2 weeks	53	3,300	50.0	10 —	108	7,300	68.5
3 weeks	57	3,800	52.0	11 —	81	7,600	69.5
1 month	146	4,300	53.5	12 —	83	7,600	70.0
2 months	153	5,150	57.0	13 —	67	7,950	71.5
3 —	156	5,750	59.5	14 —	48	8,050	71.5
4 —	132	6,300	62.0	15 – 17 —	107	8,450	73.0
5 —	132	6,650	63.5	18 – 20 —	54	9,050	75.5
6 —	117	6,950	65.0	21 – 23 —	35	9,300	78.0
7 —	130	7,000	65.5				

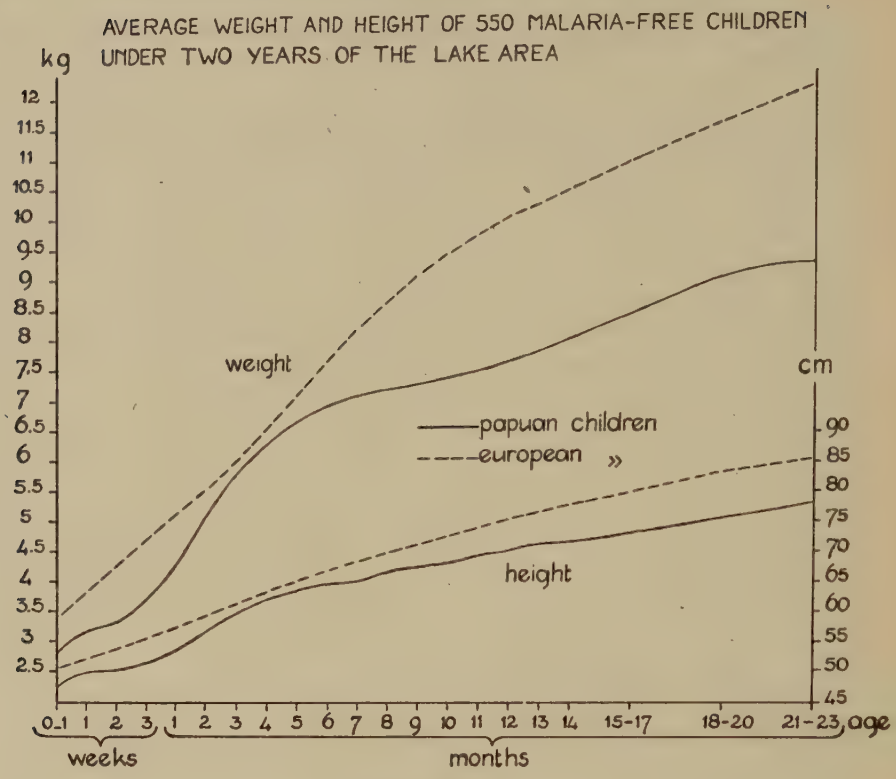

AVERAGE WEIGHT AND HEIGHT OF 550 MALARIA-FREE CHILDREN
UNDER TWO YEARS OF THE LAKE AREA
kg
cm
weight
height
papuan children
european »
0-1 1 2 3 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15-17 18-20 21-23 age
weeks
months

FIG. XIV.

those of the latter. This may be due to chance, but a different explanation might also obtain.

The individual inhabitant of a malarious area may benefit both directly and indirectly from malaria control. Directly because he suffers less or not at all from the disease; indirectly because better health often means greater prosperity for the community. And in underdeveloped countries, greater prosperity usually means more and/or better food. Since, in holoendemic regions, this indirect improvement will manifest itself only slowly, it is in itself not illogical to expect that the average of weight and height will show improvement for several years after malaria control has become effective. This may serve also as an explanation of the higher values of weight and height two years after spraying.

CHAPTER V

CLASSIFICATION OF MALARIA

A. The "Kampala" Proposals

The Malaria Conference in Equatorial Africa, held at Kampala, Uganda (WHO, 1951), proposed a working classification for malaria endemicity which, for the sake of simplicity, is based only on the spleen rate in relation to age. According to this classification, malaria is labelled "hypo-endemic" when the spleen rate in children aged 2—10 years is under 10% and meso-endemic, when the spleen rate in this age-group is between 11% and 50%. "Hyper-endemic" are those areas, where the spleen rate in children aged 2—10 years is constantly over 50%, and high in adults, while malaria is "holo-endemic" in areas where the spleen rate in children is constantly over 75%, but low in adults.

From the report of the Conference it appears, moreover, that holo-endemic malaria is supposed to be accompanied by an absolute parasite rate approaching 100% early in the second year of life, and subsequently declining throughout life, while the parasite density declines rapidly between the second and fifth year and then more slowly. The decline in all these malariological rates in the elder age-groups is explained by increasing immunity. The Wilson's (1936, 1937, 1938) were among the first to draw attention to this peculiar course of the various malariological indices. Their observations concerned the Digo-Bantu, a tribe in Tanganyika of about 600 people, who were investigated every two months for a period of 21 months.

At first Swellengrebel (1948 a) did not accept that the spleen rate in holo-endemic areas necessarily declines with advancing age. Considering it is not impossible that there might also be racial differences in the reactions of the spleens, he expected to find in New Guinea a degree of malaria comparable to that in highly malarious areas of Africa, but not accompanied by a declining spleen rate. However, a visit to this island caused him to accept the views of the Wilson's. The spleen rate in the areas investigated by him in New Guinea (1949) declined more than he expected them to do, while the heavy infection rate was lower than in Digo-Bantu, which, in Swellengrebel's opinion, made it unjustifiable to attempt comparison with malaria conditions in Tanganyika.

However, since Swellengrebel's visit, the Malaria Division has surveyed the Nimboran Valley, in which the malariometric data appear to be such that one wonders whether the previous views of Swellen-

GREBEL do not deserve renewed consideration, without, however, dogmatically accepting the influence of race.

B. THE OBSERVATIONS IN THE NIMBORAN

Particulars of the malariological surveys and of the entomological observations in the Nimboran Valley have been described in Chapter III. The malariometric data are tabulated in the Tables XVII and XVIII, the entomological data in the Tables V, XXIII and XXIV. To demonstrate more clearly the high degree of endemicity of the area, the spleen rate,

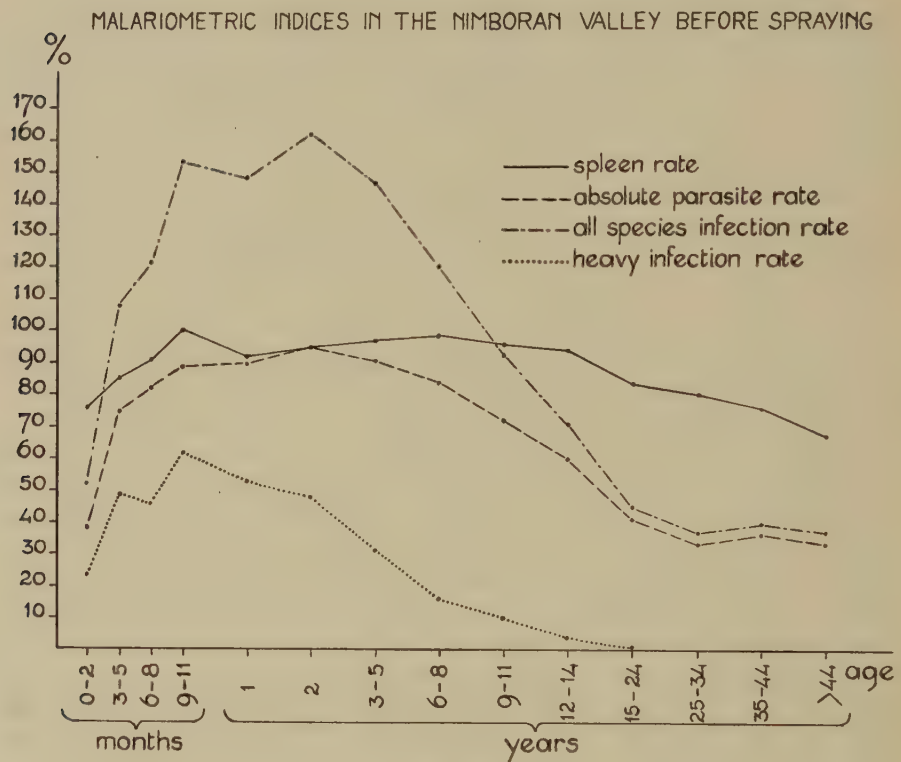


FIG. XV.

absolute parasite rate, all species infection rate and heavy infection rate are shown diagrammatically in Figure XV.

In the following paragraphs the findings in the Nimboran area are compared with data from classical holo-endemic areas in Africa.

a. *Absolute parasite rate*

On an average, the absolute parasite rate was 38% in the age-group 0—2 months, 75% in the age-group 3—5 months, 82% in the age-group

TABLE XXIX

ABSOLUTE PARASITE RATE IN NIMBORAN PAPUANS COMPARED WITH THOSE IN TWO AFRICAN TRIBES

NIMBORAN-PAPUANS, Average of several surveys			DIGO – BANTU * Average of 10 bi-monthly examinations			SIGI VALLEY - TANGANYIKA **		
Age	Number of examinations	Absolute parasite rate (%)	Age	Number of examinations	Absolute parasite rate (%)	Age	Number of examinations	Absolute parasite rate (%)
0–2 months	81	38 ± 5.4				0.5–2 months	109	21 ± 3.9
3–5 „	88	75 ± 4.6				3 – 5 „	57	75 ± 5.7
6–8 „	82	82 ± 4.3				6 – 11 „	74	88 ± 3.8
9–11 „	64	89 ± 3.9						
Total under 1 year	315	70 ± 2.6	Under 1 year	120	87.5 ± 3.0			
1 year	256	92 ± 1.6	1 year	75	100.0	1 year	62	87 ± 4.2
2 years	250	94 ± 1.5	2 years	94	100.0			
3– 5 „	488	91 ± 4.1	3– 5 „	265	98.5	2–4 years	89	96 ± 2.1
6– 8 „	450	83 ± 1.8	6– 8 „	256	80.9 ± 2.4	5–10 „	192	85 ± 2.6
9–11 „	321	72 ± 2.5	9–12 „	224	71.8 ± 3.0			
12–14 „	205	50 ± 3.5	13–16 „	155	58.7 ± 4.0	11–14 „	78	74 ± 5.0
15–24 „	391	41 ± 2.5	17–25 „	517	51.6 ± 2.2	over 14 „	83	42 ± 5.4
over 24 „	1248	34 ± 1.3	over 25 „	1320	43.6 ± 1.0			

* Derived from Table IX of WILSON (1936)

** Derived from Table I of DAVIDSON & DRAPER (1953)

6—8 months, 89% in the age-group 9—11 months and 34% in adults of 25 years and over. In Table XXIX the average of the various surveys is compared with the findings in two African tribes in Tanganyika (WILSON, 1936; DAVIDSON & DRAPER, 1953). All three agree well with each other.

b. *Heavy infection rate and parasite counts*

Our heavy infection rate is not completely comparable with the mean positive parasite count of the WILSON's. They counted parasites against leucocytes. We regarded blood as being heavily parasitized when every microscopic field of the thick film was positive; for the type of film we make, this means a density of about 500 or more parasites per cubic millimeter of blood. The heavy infection rate is the percentage of these heavy infections against the *total* number examined. For the July 1955 survey only, there was an opportunity to count parasites against leucocytes. The averages of the heavy infection rate of the surveys mentioned in Chapter III, para. B.a are shown in Table XVIII. The mean positive parasite count of the July 1955 survey is compared with the mean positive parasite count of the Digo-Bantu in Table XXX, in which, moreover is

TABLE XXX
MEAN POSITIVE PARASITE COUNT IN NIMBORAN- AND SENTANI PAPUANS COMPARED WITH MEAN POSITIVE PARASITE COUNT IN DIGO-BANTU

PAPUANS					DIGO - BANTU **		
	Nimboran		Sentani *				
Age	Number	Mean positive parasite count	Number	Mean positive parasite count	Age	Number	Mean positive parasite count
< 1 year	69	2625 ± 960	20	2915 ± 1200	< 1 year	120	7875
1 year	44	3830 ± 840	22	2950 ± 1250	1 year	75	7176
2 years	40	3010 ± 800	16	2560 ± 1200	2 years	94	4732
3-5 „	98	2335 ± 600	66	770 ± 500	3-5 „	265	1875
6-8 „	104	1120 ± 240	153	485 ± 160	6-8 „	256	555
9-11 „	72	675 ± 55	124	425 ± 180	9-12 „	224	456
12-14 „	60	155 ± 60	23	140 ± 130	13-16 „	155	216
15-24 „	46	285 ± 220	21	15 ± 7	17-25 „	517	192
> 24 „	240	100 ± 45	49	12 ± 2	> 25 „	1320	190

*From SWELLENGREBEL (unpublished)
** Derived from Table IX of WILSON (1936)

included the mean positive parasite count found by SWELLENGREBEL in the holo-endemic part of the Lake Area (personal communication). From the table it is clear that differences do exist. The count for the Digo-Bantu is highest in the age-group under 1 year old, and for the Nimboran Papuans in the 1-year group. Though the rise is not significant in Papuans, it is not improbable that their parasite count really shows a maximum

in the second year of life. After this, the decline with age is constant from the 1-year-old group up and including the 12—14-year group.

The maximum parasite count in Nimboran Papuans is about half as high as that which WILSON found in the Digo-Bantu. Without being able to calculate it, I accept that this big difference is really significant. An explanation of this discrepancy is not likely to be found in a smaller infection risk. In Chapter III, para. E.c this risk was estimated to be of the order of magnitude of 150 for a Nimboran adult; WILSON (1936) calculated a risk of 30 infective bites per year for the Digo-Bantu; DAVIDSON & DRAPER (1953) of about 350 per year for inhabitants of the Sigi Valley in Tanganyika.

Another factor to be considered is the difference in the state of nutrition. In the area referred to by WILSON (1936) there was considerable malnutrition; and from the age of a few weeks breast-feeding had to be supplemented by starchy foods. Nimboran mothers are, as a rule, able to breast-feed their babies completely for five months or longer.

The opinion that breast-feeding may have a limiting influence on the number of parasites was expressed by TROWELL (1949), and is supported by recent findings of the influence of a diet of cow's milk on *P. berghei* in rats and mice (MAEGRAITH et al., 1952), and on *P. cynomolgi* in monkeys (BRAY & GARNHAM, 1953), though, so far, this influence could not be demonstrated in human malaria (MILLER, 1954; COLBOURNE & SOWAH, 1956). Results of quite a different sort of experiments by BRUCE-CHWATT (1954), BRUCE-CHWATT & GIBSON (1956) and FERRY (1956) indicate that in rats humoral immunity to infection with *P. berghei* can be transmitted through the milk of immune mother-rats. Innate immunity in children born of immune mothers, and giving protection in the first few months of life, has been observed by many authorities, e.g. BARBER et al., (1937); HACKETT (1941); GARNHAM (1949); SWELLENGREBEL (1950); BRUCE-CHWATT (1952). The presence of circulating anti-bodies, — which could be transmitted transplacentally or through the milk —, though difficult to demonstrate, is made likely, inter alia, by experiments with *P. knowlesi* and *P. inui* in monkeys (COGGESHALL & KUMM, 1937), with *P. lophurae* in chicken (SCHWINK, 1954), and with *P. berghei* in mice (ROBERTS, 1954).

Taking into account what has been observed and what is known from experiments it may be concluded that, as a rule, the breast-fed Nimboran Papuan infants also succeed in limiting the number of their malaria parasites. They do so to even lower numbers than the malnourished Digo-Bantu babies. This points to the possibility of nutritional influences, and the present investigations tend to stress the evidence that one or other of the mechanisms mentioned above as active in animal malaria, may operate in Nimboran Papuan infants also.

When passive immunity wanes and supplementary food is provided, active immunity is in most cases apparently strong enough in the Nim-

boran infant to prevent casualties, though the number of parasites rises to a maximum in the second year of life. This rise was not seen in the Digo-Bantu examined by WILSON, nor in the people in Tanganyika more recently seen by DAVIDSON & DRAPER (1953). MACKERRAS & ABERDEEN (1946) found the highest parasite counts in Papuans of Wewak to occur in the first year of life as well. However, the infants of their survey were born of war-refugees, who, shortly before the survey, had been suffering from malnutrition and disease.

The possibility, that foetal- and/or abnormal haemoglobins may also have a limiting influence on infant parasite counts and parasite rates is discussed in a following paragraph.

c. *Sickness*

The observations on the infants examined in the various surveys do not point to much sickness from malaria as long as they are breast-fed, and it was not often necessary to provide them with anti-malaria drugs. In the July 1955 survey, sixty-nine infants were examined and forty-four were found positive, of which only three had 20,000 parasites or more per cmm of blood.

Gain in weight is as a rule constant as long as the infants get sufficient milk from their mothers. From Table XXVII and Figure IX it may be seen that this continues for about five or six months. Most infants present a reasonable or perfectly healthy appearance for the first seven or eight months, while obvious ill-health can often be attributed to diseases other than malaria. By the end of the first year and during the second year of life some protein deficiency is most likely; they often look more anaemic, and probably suffer more from their parasite burden than before. With increasing age the mean positive parasite count drops again. Though a feverish child may sometimes be found at school, the attacks of malaria are mild and of short duration. In adults, even such mild attacks are very rare. In the July 1955 survey, 20,000 or more parasites per cmm of blood were seen only ten times, apart from those in infants, the oldest with this high number being a child of 5 years.

It is not pretended to claim that Nimboran infants are not affected at all by their malaria infections. We have no idea how many children, either directly or indirectly, die of malaria. Infant mortality is heigh in New Guinea and often surpasses 30 per cent. One cannot escape the impression that malaria has something to do with it, as it also probably has with the general lassitude and lack of energy often observed in adults. Moreover, as was discussed in Chapter IV, weight and height were, in Nimboran children, on the whole lower than in Sentani children, especially at the age of maximal parasite load (Figures IX and X).

d. *Ratio between species of malaria parasites*

There is also a difference between the ratios of the three species of

malaria parasites in Nimboran Papuans on the one hand, and that in Digo-Bantu on the other. These differences are shown in Table XXXI. In the Digo-Bantu *P. falciparum* prevails markedly over the other species, while immunity is developed more rapidly against the latter than against the first, resulting in a more rapid decline with age of the incidence of *P. vivax* and *P. malariae*. It is supposed by WILSON that the most "strong" and dangerous parasite is able to push back the others, a phenomenon also found for *P. cynomolgi* and *P. inui* in monkeys (SINTON & MULLIGAN, 1933; JASWANT SINGH & RAY, 1952). Though FAIRLEY (1945) also for South Pacific strains of *P. falciparum* and *P. vivax* observed that, when they are in competition on equal terms in European volunteers, *P. falciparum* breaks through and *P. vivax* is suppressed, these tendencies are less apparent in Nimboran Papuans, in whom *P. falciparum* just significantly prevails over *P. vivax* between 1 and 24 years of age only. Over 24 the difference is not significant; in the 0—1-year age-group, *P. vivax* is the predominant species. Moreover, the rapidity of decline with age is almost equal for both species, resulting in a practically equal representation in adults. Many of these tendencies were also observed in a Papuan tribe near Wewak (MACKERRAS & ABERDEEN, 1946). There too, *P. vivax* was predominant in infants only. In older age-groups the predominancy of *P. falciparum* was more marked than in the Nimboran, but a number of the children had been recently exposed to epidemic conditions.

COATNEY and co-workers (1948, 1950) revealed that one of the characteristics of the Chesson strain of *P. vivax*, which originates from New Guinea, is the frequency of its relapses, an interval of six weeks being the rule. FAIRLEY (op. cit.) had noticed this too, it was observed in ex-service men from the South Pacific (COGGESHALL, 1945; GORDON et al., 1945) and this quality is also well known to clinicians in New Guinea. New Guinea strains of *P. vivax* are apparently not easy to suppress, while the frequency of relapses in itself must result in frequent findings during surveys.

On the other hand, LAMBERT (1949) is of the opinion that Melanesian malignant tertian malaria, both in Europeans and in natives, is less often fatal and less severe than the Costa Rican variety. This might imply that the New Guinea strains of *falciparum* parasites are less strong and less capable of suppressing relatively strong or virulent (YOUNG et al., 1948) *vivax* strains.

When comparing the relative incidence of both species of parasites in different races, one must also bear in mind the high degree of resistance to infections with *P. vivax*, often observed in negroes (BOYD & STRATMAN-THOMAS, 1933; YOUNG et al., 1955).

Immunity to local strains of *P. malariae* is also less rapidly developed in Nimboran Papuans than in Digo-Bantu. In the former, this species is still well represented at the adult age.

TABLE XXXI

FREQUENCY OF MALARIA PARASITES BY AGE, IN NIMBORAN PAPUANS AND DIGO-BANTU

Nimboran Papuans									Digo-Bantu *)				
Age-groups (years)	Number of surveys	Number examined	P. falciparum		P. vivax		P. malariae		Age-groups (years)	Number examined	P. falciparum %	P. vivax %	P. malariae %
			Number	Per cent.	Number	Per cent.	Number	Per cent.					
0— 1	7	282	119	42.2±2.9	146	51.8±3.0	44	15.6±1.2	0— 1	120	82.5	20.0	37.5
1— 5	5	887	517	58.3±1.7	451	50.8±1.7	345	38.9±1.6	1— 5	393	84.7	20.1	41.7
6—11	5	761	332	43.6±2.0	268	35.2±1.7	238	31.4±1.7	6—10	396	63.4	4.5	11.4
12—24	4	596	140	23.5±1.7	107	18.0±1.6	72	12.1±1.3	11—20	439	39.6	1.6	7.5
over 24	4	1265	184	14.5±1.0	173	13.7±1.0	125	10.0±0.8	over 20	2045	22.0	0.9	4.0

* Derived from Table XIII of WILSON (1936)

e. *Infant parasite rate*

The same problem as that encountered in other highly endemic regions, viz. the discrepancy between the high number of infections which can be calculated from entomological observations and the relatively slow rate at which infants are infected (DAVIDSON & DRAPER, 1953; DAVIDSON, 1955; COLBOURNE & WRIGHT, 1955; MACDONALD, 1955) is met with in the Nimboran. Exposure to a risk of about one infective bite in every two days, in the Nimboran, ought to result in a parasite rate approaching 100 per cent. at a much earlier age than is, in fact, the case (Table XVIII, Figure XV). The time that this maximum is reached can be calculated with help of the formula (MACDONALD, 1950 a):

$$t = \frac{4{,}60}{h - mh}$$

in which

t = the period of exposure in days to the risk of parasitaemia (which is less than the infants' ages by the duration of the incubation period);
h = the inoculation rate, or the proportion of the population receiving infective inocula in one day;
m = the proportion of infections resulting in death.

For one infective bite in two days, h is 0.5, while m, in the case under consideration, can be neglected without material error, from which results that $t = 9.2$, which means that the maximum of parasitaemia must be reached within three weeks of birth.

When some allowance is made for the probability that infants are bitten less frequently by mosquitoes, and it is arbitrarily assumed that exposure to the risk of infective bites is of the order of one in seven days, then the maximum would be approached at the age of 1½ months.

Theoretically, parasite rates of 35% for the age-group 0—2 months, and of 78% for the age-group 3—5 months are possible with an inoculation rate of 0.0123, or one infective bite in every 81 days (4.5 infective bites per year). This inoculation rate is calculated with the aid of the formula (MACDONALD, 1950 b):

$$h = \frac{\log (1 - x)}{-0.4343t}$$

in which

h = the inoculation rate;
x = the proportion of the population with parasitaemia (in the cases under consideration about 0.4 and 0.75 respectively);
t = the median age of the group in days, corrected for the incubation period (35 and 127 days respectively).

In Figure XVI a theoretical curve, based on $h = 0.0123$, is shown

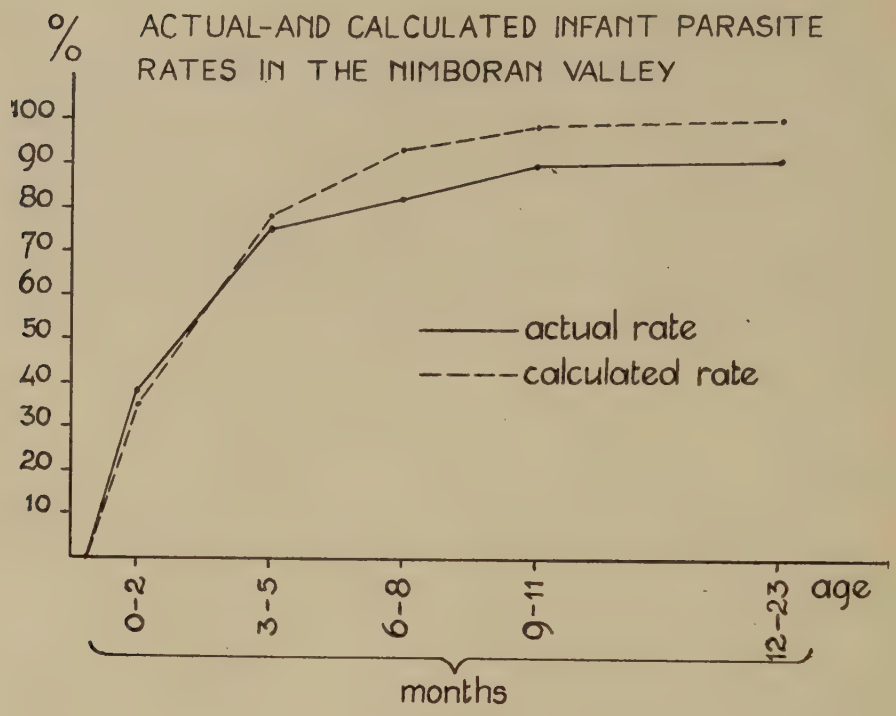


FIG. XVI.

besides the actual curve of the Nimboran infant parasite rate. The observed and calculated values are:

Age	Corrected median age in days	Percentage positive: observed	calculated
0—2 months	35	38	35
3—5 „	127	75	78
6—8 „	218	82	93
9—11 „	310	89	98
1 year	540	90	99.9

The calculated values were obtained with the aid of the formula (MACDONALD, 1950 b):

$$x = 1 - e^{-bt}$$

in which e = the base of natural logarithms: 2.71828.

Because the curve of infant parasite rates of the Nimboran shows a bend after the age of 5 months, it is impossible to find values for the inoculation rate with the aid of which a theoretical curve can be drawn which neatly fits the actual one along the whole of its course to its

maximum. The bend is probably due to the fact that in the Nimboran the majority of the infections under 1 year are *P. vivax* infections. For, the theoretical curve presumes that superinfections are possible, which may be true for *P. falciparum* infections. In *P. vivax*, however, superinfections with homologous strains usually fail (JAMES, 1931), though COOPER et al. (1947) had success with superinfection by means of trophozoites, injected four months after the initial sporozoite-induced infection.

Several possible reasons have been brought forward for the discrepancy between the inoculation rate derived from entomological observations, and that derived from infant parasite rates. MUIRHEAD-THOMSON (1951 a) observed that older children and adults are more attractive to anophelines than infants and toddlers, but it is shown above that, when ample allowance is made for this fact, the discrepancy is still marked. BRUCE-CHWATT (1948) and DAVIDSON & DRAPER (op. cit.) suppose that the passive immunity, obtained from the immune mother, may be of importance. The possible influence of nutritional factors has been discussed in para. B.b. ALLISON (1954) thinks of relative insusceptibility of erythrocytes, containing foetal or sickling haemoglobin. MACDONALD (1955) looks for an explanation to the low gametocyte densities in the highly immune, which, for the greater part, constitute the inhabitants of holo-endemic malarious regions. According to this author, these low gametocyte densities must result in low and partly ineffective sporozoite densities in mosquitoes. But whatever may be the cause or causes of the slow rate of increase of infant parasite rates, the phenomenon is typical of holo-endemic malaria.

So far, the observations in the Nimboran are much in accordance with those in other regions qualified as holo-endemic. However, an important difference will become apparent when comparing the spleen rates of Nimboran Papuans with the spleen rates in these holo-endemic areas.

f. *Spleens*

The average spleen rate from five surveys of Nimboran Papuans, based on 3636 palpations, is compared in Table XXXII with the spleen rates of two African tribes in Tanganyika. The high rates in the older age-groups of the Papuans are striking. The differences between Papuans and Africans are significant in the 5—10-year age-group and older. The average enlarged spleen declines in Digo-Bantu from a maximum of 3.6 to 0.8 (Schüffner's classification) at the age of 25 years. These figures are 3.2 and 1.9 in Nimboran Papuans. Thus, in New Guinea we find that the spleens of Papuans remain constantly and considerably enlarged throughout their lifetime in spite of endemic conditions, which in other regions are accompanied with a marked decrease in the spleen rate and in the size of spleens in adulthood.

We made yet another observation in New Guinea which points to the fact that Papuan spleens do not readily retract below the costal margin,

TABLE XXXII
COMPARISON OF THE SPLEEN RATE IN NIMORAN PAPUANS WITH THOSE IN TWO AFRICAN TRIBES

Nimboran Papuans		Digo-Bantu *		Sigi Valley, Tanganyika **	
Age (years)	Spleen rate %	Age (years)	Spleen rate %	Age (years)	Spleen rate %
Under 1	80 ± 2.6	Under 1	89 ± 2.8	Under 1	51 ± 3.2
1 — 5	95 ± 0.7	1 — 5	93 ± 1.2	1 — 4	89 ± 2.5
6 — 11	97 ± 0.6	6 — 10	77 ± 2.1	5 — 10	73 ± 3.2
12 — 24	87 ± 1.3	11 — 20	44 ± 2.4	11 — 14	53 ± 5.7
Over 24	78 ± 1.2	Over 20	39 ± 1.2	Over 14	26 ± 4.8

* Data derived from WILSON (1936)
** Data derived from DAVIDSON & DRAPER (1953)

once they have been enlarged for some time by malaria. A total of forty-nine Papuan pupils at a boarding school, aged 13—19 years, were given 25 mg of Daraprim once weekly during a period of 15 months; forty-nine others served as controls. The boys may be regarded as semi-immunes. Before the experiment started, both groups experienced malaria attacks, with positive blood findings. In the course of the experiment positive blood slides were found regularly in the control group only. Nevertheless, the spleen rate of the Daraprim-treated group only fell from 79% ± 5.8% to 63% ± 6.9%, which is not a significant fall. The rate of the control groups changed from 73% ± 6.3% to 77% ± 6.0%.

That a spleen rate should not fall significantly after 15 months of prophylactic drug-intake is unusual, and deviates from experiences elsewhere (e.g. DE ROOK, 1949; VAN GOOR et al., 1950; HIMPE & PIERQUIN, 1950; MASSEQUIN & POLINACCI, 1953; MILLER, 1954; FARINAUD & CHOUMARA, 1954).

Moreover, as was discussed in Chapter III, para. D.a. 1 and 2, spleens in the Lake Area, after spraying, were also reluctant to retract below the costal margin, once they had been enlarged by malaria for some years (Figure I and V).

One way in which an explanation of these facts must be sought is surely to look for morphological differences between spleens of adult Papuans and of adult African negroes from highly endemic malarious regions. We were able to obtain only eight pieces of Papuans' spleens from holo-endemic areas in New Guinea and nine pieces from African negroes [1]). Unfortunately it was not known whether the negroes had lived in holo-endemic malarious regions, though all must have suffered from

[1]) I am indebted to Lt. Col. WALTERS of the West African Council for Medical Research for these pieces of spleen.

the disease. Only a few of the total of seventeen had died from accidents, the others from all kinds of diseases. Sections were stained in the Laboratory for Pathology of Leyden University, and examined with the assistance of the pathologist H. C. M. VAN DER SCHOOT. With the small material no definite conclusions could be arrived at. It was expected (METSELAAR, 1957) to find excessive fibrosis of the Papuan spleens but this could not be confirmed. Sections stained according to von Gieson did not show abnormal prevalence of collagenous fibers in the pulp; the capsules and trabeculae only were thickened. Hematoxylin-eosin stained sections presented the appearance of active spleens with reticular hyperplasia, but without any specific features. There was a regular distribution of white and red pulp. Sections stained according to Gömöri's silver-impregnation method showed an abundance of reticular fibers, but this is usually seen in chronic malaria (ROTTER & BÜNGELER, 1955), and was also present in six of seven Papuan spleens from less endemic areas, and in the spleens of the African negroes. Examination of a larger and better selected material must therefore give a definite answer to the problem whether there are morphological factors which could explain the difference in spleen size which is found between adult Papuans and adult negroes from highly endemic malarious regions. Our material did not support the supposition.

VISWANATHAN (1951 a and b) introduced a new classification of malaria, in which "super-endemicity" is distinguished from "holo-endemicity". In super-endemic malaria, the highest degree of tolerance in adults is represented. It should be present only in races (such as the oldest tribes in India) for centuries exposed to frequent malaria infections, as a result of which a natural selective tendency towards a very high degree of tolerance has developed. The main characteristics of this super-endemic malaria are: firstly, very little sickness in infants; secondly, high parasite counts in these infants because, as a result of little sickness, the development of antibodies against the parasites is reduced; and thirdly, the practical absence of symptoms of malaria in adults, in whom tolerance is accompanied by a low spleen rate. In VISWANATHAN'S type of holo-endemic malaria, which is developed in races that have been exposed to malaria for a limited number of generations only, the parasite counts in infants are low and the spleen rates in adults high.

I do not think it necessary to accept VISWANATHAN'S views as completely applicable to New Guinea conditions. For the relatively small mean positive parasite counts in Nimboran infants, explanations other than lack of racially determined tolerance were put forward. Moreover, the experiments by FABIANI & ORFILA (1954) seem to indicate, that in mice on a milk diet the combination of little sickness, low parasite counts and development of anti-parasitic immunity against *P. berghei* is possible. Apart from this, Papuans too must by now have been exposed to malaria infections for many centuries.

In relation to the problem under consideration, one wonders whether the protection against malaria, which sickle cell haemoglobin gives to persons with the sickle-cell trait (ALLISON, 1954, 1956; RAPER, 1955; DELIYANNIS & TAVLARAKIS, 1955), has something to do with the small spleens which in some races are found at adult age. In a malarious region of low endemicity in northern Rhodesia, BEET (1947) and BRAIN (1952) found that in sicklers enlarged spleens were less common than in non-sicklers. In young children parasite counts in *P. falciparum* infections are also much lower in sicklers than in non-sicklers (RAPER, op. cit.). But because the protective action of sickle-cell haemoglobin is only a relative one, a high degree of immunity will nevertheless develop in persons living in highly malarious regions, and the limiting action on the parasite counts and parasite rates, exerted by sickle-cell haemoglobin, will be overshadowed in older children and adults by the limiting action exerted by immunity (RAPER, op. cit.; WOODRUFF, 1956). Neither, however, is the limiting action on the spleen rate of sicklers any longer detectable in sicklers living in those areas. Because of the selection which results from the protection against malaria, the highest proportion of sicklers is found in malarious regions of highest endemicity (ALLISON, 1956). In those regions spleen rates in young children approach 100 per cent., notwithstanding a percentage of sicklers that may go as high as forty. It seems, however, not unreasonable to expect that, once immunity is well established, and spleens become smaller, the size of spleen in sicklers will be reduced more than that of non-sicklers. In this way the sicklers could contribute to a lower spleen rate in adults. This needs investigation. Should a relationship become apparent between the sickle-cell trait and small spleens in adulthood in holo-endemic areas, then this could not only explain that low adult spleen rates are common in Africa, but it could also give an explanation of the fact that such rates are found in those parts of India which are inhabited by the oldest tribes of that country (VISWANATHAN, op. cit.). In these tribes, sicklaemia was detected by LEHMAN & CUTBUSH (1952).

So far, the sickle-cell gene has not been found eastward of India (SWINDLER, 1955). In Hollandia we examined 319 blood-samples of Papuans for sickling, but no sickle-cells could be detected.

Sickling alone cannot sufficiently explain the divergence of adult spleen rates in Africa and New Guinea, because the difference is sometimes greater than the percentage of sicklers in the African negroes. CLARK (1928) is of the opinion that race may play an important role in spleen size. He found that extreme cases of splenic enlargment were very rarely seen in autopsies of negroes, but often in Latin Americans of other races. A comparable phenomenon was seen by GIGLIOLI (1939, quoted by HACKETT, 1941). SWELLENGREBEL (1948 a), too, does not preclude the possibility of racial influence on spleen size.

The difference in spleen rate of adult negroes and adult Papuans might

also be explained by the difference in the prevalence of parasite species. Owing to the high degree of resistance against *P. vivax*, this species is seldom found in adults of the negro race (para. d; Table XXXI). It is, however, still well represented in adult Papuans. These facts may have a bearing on spleen size, though it is not well understood why the less offensive parasites of *P. vivax* should cause larger spleens in Papuans than the more dangerous parasites of *P. falciparum* in negroes.

There is an indication that nutrition might have some influence on spleen size. VOORS (Second Quarterly Report 1955, Malaria Division) found differences between the average spleen sizes of adults in two adjacent villages in New Guinea, situated along the coast not far from Hollandia. The inhabitants of one village have been fishermen for many generations; the inhabitants of the other village originate from a valley more inland, and largely depend for their proteins on (less productive) hunting. Although exposed to the same risks of malaria infections, the average spleen size of the fishermen is significantly smaller. However, without comparative studies, the assumption that nutrition in Africans is better than in Papuans is not justified.

Finally, the difference might be explained by differences of pathogeographical origin which are not yet understood.

There is still another peculiarity about Papuan spleens. The absolute parasite rate in infants of the Nimboran, which is 38% in the first three months of life, rises through 75% and 82% to 89% in the fourth quarter. The spleen rate is 76%, 85%, 91% and 100% respectively for the four quarters (Table XVIII). The spleen rate thus rises well ahead of the absolute parasite rate (Figure XV), which means that spleens in Nimboran infants are to a certain extent enlarged independently of malaria. The same was observed in the infants that remained free of malaria after spraying of the area with dieldrin. The figures (partly derived from the Second Quarterly Report 1956, Malaria Division) are shown in the following table.

Age (months)	Number	Number enlarged	Spleen rate %	Average spleen	Average enlarged spleen
0	17	10	59	0.6	1.0
1	22	15	68	0.7	1.0
2	22	16	73	0.8	1.1
3	17	16	94	1.4	1.5
4	20	16	80	1.1	1.4
5	5	3	(60)	(0.8)	(1.3)

In the Lake Area the same phenomenon was seen in a much greater material, because the control infants there could be observed for a much longer period. The results of 2502 spleen palpations on about 550 infants in 1954, 1955 and early 1956 are summarized in Table XXXIII. Apart

TABLE XXXIII

SPLEEN-INDICES OF MALARIA-FREE CHILDREN FROM THE LAKE AREA.

Age (months)	Number	Number enlarged	Spleen rate %	Average spleen	Average enlarged spleen
0	237	52	22	0.2	1.0
1	250	97	39	0.4	1.1
2	240	135	56	0.7	1.1
3	234	141	60	0.8	1.2
4	207	129	62	0.7	1.1
5	171	110	64	0.8	1.3
6	171	118	69	0.8	1.2
7	154	99	64	0.8	1.2
8	125	74	59	0.8	1.3
9	133	78	59	0.7	1.2
10	108	54	50	0.6	1.2
11	83	37	45	0.5	1.2
12	85	43	51	0.6	1.2
13	64	17	26	0.3	1.2
14	43	17	40	0.5	1.2
15	47	16	34	0.4	1.1
16	28	9	32	0.4	1.1
17	32	5	16	0.2	1.0
18–20	57	13	23	0.3	1.4
21–23	33	4	12	0.1	1.0

from the infants who had contracted malaria, none was excluded from the series. A regular increase in spleen rate and spleen size in the Sentani infants for the first six months of life is evident from the figures. Later on a fall is seen. A spleen rate of 22% ± 3% is present in the first month of life. It rises then to a maximum of 69% ± 4% at the age of 6 months, after which the percentage falls again to 12% ± 6% in the last quarter of the second year.

A curve of this type is more or less observable in all the diagrams of spleen rates in Figures I, V and XV. That the spleen rates in the youngest age-groups are smallest in the first surveys may be explained by the fact that, during the consequent surveys, we were more keen on the phenomenon and looked more closely for the small and soft spleens in infants. Only a few large spleens were present, viz. in the Lake Area seventeen spleens III and one spleen IV. Comparison of Table XXXIII of Sentani infants with that of Nimboran infants (above) plainly shows that the spleen rate of the latter is higher. The probability that the differences are due to chance is less than 5 per cent. for the age-groups from 0 to 2

months, incl., and less than 0.3 per cent. for the 3-month group. For the 4-month group the difference is not significant.

Palpable spleens are not pathological in infants, though the high rates found in the Lake Area and the Nimboran, seem unusual. The highest percentage found in the literature is that recorded by ZAMKIN (1925, quoted by SPICER, 1945), who observed 43.1% palpable spleens in 541 infants under 2 years in the United States. This percentage is of the same order of magnitude as our series from the Lake Area (49.9%) but in the Nimboran the percentage is most probably much higher. MACKERRAS & ABERDEEN (op. cit.) observed large numbers of enormous spleens in very young children at Wewak, Australian New Guinea, and speak of a "suggestion that many infants may be born with large spleens". These spleens sometimes extended into the right iliac fossa, and, according to the authors, were firm and did not feel like the soft, turgid ones of acute malaria. In our experience the malaria spleens were distinctly firmer than the spleens of malaria-free infants; the enlargement at Wewak might, therefore, have had a different cause.

At Leyden, Rijnsburg and Noordwijk in the Netherlands, I examined 221 infants under 1 year, who attended infant welfare clinics. None was excluded. The spleens of forty-two were palpable (19%). Of the ninety-one infants from the city of Leyden twenty-three had palpable spleens (25.3%); of the 130 children living in the rural municipalities, nineteen spleens could be palpated (14.6%). The probability that the difference is due to chance is, however, slightly more than 5 per cent., and not significant according to statistical rules. It is, therefore, not proved that also in the Netherlands local differences can be observed in spleen rates of infants. Only small spleens, size I, were found in the series. The figures are too small for further analysis. The rate is much lower than that of the New Guinea series.

In Noemfoor, an island in the Geelvink Bay, north of New Guinea, JANSSEN (Second Quarterly Report, 1955, Malaria Division) found a positive correlation between palpable spleens and palpable livers in infants of whom only a few were infected with malaria. VAN DER HOEVEN (op. cit.) thinks of the possibility that the liver enlargement, which is often present in malnourished children, may cause portal hypertension, which, in turn, may result in splenic enlargement; an opinion which is expressed with much reserve by that author. In this case one would expect a rise in the infant spleen rate after the age of 6 months, when breast-feeding is partly substituted by other food. However, in Sentani infants a drop is apparent, and it is therefore unlikely that this explanation will often do, the more so, as other symptoms of portal hypertension in young children were not seen in the Lake Area.

BRUCE-CHWATT (1955) observed a significantly higher weight of spleens in autopsies of African new-born from Lagos, Nigeria, compared with that of spleens of English new-born. Taking into account the mean

weight at birth, he calculated that the spleen weight of the latter is about 40% less than that of the former. He raises the question whether it could be "that among the maternal antibody complex, passing across the placenta, there is an immune fraction which has a specific effect on the foetal lymphoid-macrophage system generally, and on the largest single collection of mesenchymal macrophage tissue in particular by activating it in utero, in preparation, as it were, for the early encounter with the malaria parasite". Assuming that this supposition is true and holds good also for New Guinea, it does not explain the rise after birth of the spleen rate in Sentani infants, unless the hypothesis is extended to the passage of such activating antibodies together with the milk. If true, this type of splenic enlargement in infants will disappear when immunity of the mothers wanes as a result of control measures.

Our attempt to look for a possible relation between anaemia and splenic enlargement failed, because the chemicals necessary for the Sicca haemometer appeared to deteriorate rapidly in Hollandia. Tallquist's method was rejected for this investigation.

Greater risk of infections to which Papuan infants are exposed compared with infants in more advanced countries, might be another cause of the larger spleens in the former, but all such explanations are, at present, hypothetical.

At any rate, our observations support the opinion, expressed by RUSSELL (1935), that children below 2 years of age should be excluded from a splenic index. The average enlarged spleen-size of this age-group might be of more importance.

g. *Discussion of the classification of New Guinea malaria*

MACDONALD (1952 b) recently introduced a new classification of malaria, in which he distinguishes "stable" and "unstable" malaria. Stable malaria occurs, as a rule, in areas with perennial transmission. The factors which affect malaria, like anthropophily and longevity of the vectors, duration of the extrinsic cycle, etc., result in such an amount of infections that a large proportion of the human population is infected at an early age and a high degree of immunity is developed in older children and adults. Overlapping of infections often occurs, both in man and in mosquitoes. In areas with such stable malaria, epidemics are not likely to occur. On the other hand, when climate and/or bionomics of the vector are such that immunity of the population can only be slight, a change in one of the factors may cause enhanced transmission, which, in turn, may result in epidemics. Periods of enhanced transmission may happen either each year, as in seasonal malaria, or with longer intervals. In areas where such epidemics are likely to occur now and again, unstable malaria prevails. A classification based on endemicity, as that of the Kampala conference, should, according to MACDONALD, be subordinate to the main classification into stable and unstable malaria.

Malaria in the Nimboran is certainly stable. With regard to the Kampala classification, the absolute parasite rate found in Nimboran Papuans, and the decline in parasite counts after the second year, agree very well with holo-endemic malaria, while the relatively low parasite counts are not in disagreement with the characteristics of this degree of malaria endemicity. The basic factor which determines this degree — viz. the number of infections per year — can, as has been discussed (Chapter III, para. E.c), be estimated in Nimboran Papuans at 150 or more per adult, well divided over the year. This, too, is well within the definition of holo-endemic malaria, even if a number of sporozoite-positive anophelines should not be infective. Only the spleen rate runs a peculair course: in adults it is higher than that suggested for holo-endemicity. The observations on Papuan schoolboys who took suppressive drugs, and those on the population of the Lake Area two years after insecticide spraying, almost compel one to the conclusion that Papuan spleens do not readily retract below the costal margin once they have been enlarged for some years by malaria.

A definite explanation for this fact cannot be given, but several possible reasons for the difference from what is seen elsewhere are discussed in para. f. The spleen rate is only secondary to the number of infections and to the absolute parasite rate. When the latter two are consistent with holo-endemicity, while the former does not, then it seems illogical to use the former as a yardstick. I think I have made it clear that the Nimboran Valley is one of the regions with the highest possible degree of endemicity. But the determination of the spleen rate is not the way to assess this.

On the other hand, the Kampala standard of holo-endemicity can rightly be applied to the spleen rate found in some islands east of New Guinea (BLACK, 1954 a and b), but where conditions differ radically from those prevailing in Africa. To obtain an insight into malariological conditions in New Guinea and the adjacent islands, more extensive surveys are necessary. These surveys should, at least, include an assessment of the absolute parasite rate, while parasite counts, especially in infants and young children, will be extremely useful.

Because the primary factors inherent in the highest degree of malaria endemicity are found in the Nimboran, this area was classified as holo-endemic in the previous chapters.

In the western Lake Area, not such extensive entomological observations were made as in the Nimboran Control Area. "Whole-night" catches, to assess the number of anopheline bites per man, were not made. But during the catches at Dojo an average number of 10 anophelines per man was certainly caught during part of the night only, even after spraying. A number of 20 anophelines per man per night, or about 7000 bites per year, will, therefore, be a realistic estimate. With a sporozoite rate of 1%, this would mean about 70 bites of positive anophelines per man per year, which is well within the definition of holo-endemic malaria

(WILSON et al., 1950). The western Lake Area is, therefore, also called holo-endemic in the previous chapters.

Some doubt may rise whether the absolute parasite rate fits this definition, because its maximum is relatively low. As was, however, discussed in para. b, better nutrition has a favourable effect on malaria infections. It is not unlikely therefore that the Sentani Papuans show still more resistance against malaria than the Nimboran Papuans, which may result in lower mean positive parasite counts (Table XXX, SWELLENGREBEL's figures), and a lower maximum of the absolute parasite rate (Table XV A).

Malaria in the inhabitants of the eastern Lake Area, so far classified as meso-endemic, is certainly unstable, as was proved when a number of people settled in Waina: it was not long, before an epidemic occurred (Chapter III, para. D.b).

CHAPTER VI

DISCUSSION AND PROGNOSIS

When, in 1952, it was decided to undertake in Netherlands New Guinea a pilot project of malaria control with residual insecticides, the fame of residual spraying in general, and of DDT in particular, had reached a pinnacle. Successful campaigns had been carried out in several parts of the world, e.g. in Ceylon, India, Italy and British Guiana, while many promising projects were in operation. Though there were some indications of possible resistance in *A. sacharovi* in Greece (LIVADAS, 1951, quoted by GEORGOPOULUS, 1954), this did, on the whole, not arouse so much anxiety among malariologists. The fact was explained by the simultaneous use of DDT as a larvicide and as an imagocide, an explanation which held good also when resistance in *A. sundaicus* from Java (CRANDELL, 1954) was reported.

With regard to New Guinea, this simultaneous use could be avoided. In that island we were therefore not yet, by that time, on the horns of the dilemma "all or nothing". It was clear to us that eradication of malaria by means of residual insecticide spraying could not be expected, owing both to the bionomics of the vector species and to the impossibility to cover the whole of the territory within a measurable space of time. But abatement of malaria, even if the application of insecticides had to be continued for many years to come, seemed at least a useful purpose. The pilot project was necessary to assess the degree of improvement which could be achieved. Its results far exceeded expectations.

Experiments in window-trapped houses before spraying revealed that anophelines of the *punctulatus* group enter houses more readily for a blood-meal than was previously thought. Moreover, a high kill of the anophelines was obtained once the houses were sprayed. It was somewhat disappointing that persistence of dieldrin was not so long as observed elsewhere, but this is probably due to the formulation used. Persistence of DDT, compared with observations elsewhere, was satisfactory, and the killing results in the DDT-sprayed house are among the best published. This points to the possibility that anophelines of the *punctulatus* group are relatively sensitive to this insecticide. However, tests to prove this supposed high sensitivity could not, so far, be made.

Short average duration of life of the vector anophelines appeared to be another favourable fact with regard to residual spraying. This short expectation of life is the most probable explanation of the relatively low sporozoite rates found in the anophelines of the *punctulatus* group (Chapter I, para. A.h).

In the field experiment with DDT in the Lake Area a considerable reduction of the malariometric indices was found two years after the first application of the insecticide, but complete interruption of transmission was, in accordance with expectations, not achieved. Two reasons can be brought forward for this. Firstly, anophelines are offered a chance to obtain a blood-meal when the villagers sit outside the houses in the evening hours. Kill by DDT inside the houses is not high enough to compensate for this, as was calculated mathematically in Chapter II. Secondly, there remain foci of transmission in the vegetable gardens and sago marshes, when people are in the habit of spending the night there now and again. These foci are not affected at all by residual spraying.

Nevertheless, one year after spraying the results were beyond expectation, and I had to decide whether extension of spraying activities to other parts of New Guinea was justified. The only objection that could be brought forward by that time was that the loss of immunity in the population which will result from residual spraying, implies a greater risk of sickness as soon as control measures have to be interrupted for some reason or other.

This problem was discussed at length at the Kampala Conference (WHO, 1951). Two schools of thought became apparent during the discussion. Adherents of the first were of the opinion that in highly endemic areas immunity against malaria is extremely effective in adults, who, they assume, are only slightly affected by the continuous infections to which these are exposed. This state of affairs should be reached at the expense of only relatively little morbidity and mortality among infants and young children, since these are protected by inherited immunity. Members of this school of thought feared that, if malaria control, once started in such areas, were to be discontinued, severe epidemics would break out, because in the meantime the population would have lost much of its immunity. This risk, weighed against the possible slight advantages, made these malariologists hesitate to introduce control measures, until intensive research had revealed beyond doubt that their ideas about morbidity and mortality in highly malarious regions were wrong.

Adherents of the second school of thought, on the contrary, held the view that in highly endemic areas immunity in adults has to be paid for by a high morbidity and mortality in young children. They pointed to the upward demographic curves in areas of the type in which successful anti-malaria campaigns were in operation. Moreover, these malariologists were not convinced that the health of adults in such areas does not suffer harm from the many malaria infections.

Experiences in New Guinea before spraying tended to support the views expressed by the second school. In the highly endemic areas of the island, the population is, on the whole, more backward. Before spraying, conditions in the holo-endemic part of the Lake Area compared unfavourably with those of the meso-endemic part (Chapter IV). Con-

ditions in the holo-endemic Nimboran were even worse though nutritional factors may have played a complementary part. The most enterprising people in Netherlands New Guinea live in Biak, an island in the Geelvink Bay, which is only moderately malarious.

With these examples in mind, it was thought that holo-endemic areas would benefit from residual spraying, even if transmission was not stopped completely, which assumption was strengthened by the improvement of health conditions observed in the Lake Area after spraying (Chapter IV). It was therefore decided to extend spraying to other parts of New Guinea.

By the end of 1955, areas inhabited by about 80,000 people were treated, and preliminary results in a few regions were known. These were most favourable in Biak. The number of cases treated for malaria in the local hospital and out-patient department dropped from ninety seven in November 1954 to seven in November 1955. In August 1956 only three malaria patients were treated. In April 1956 JANSSEN examined children at three clinics of the Division for Mother and Child Health in the island. The results, quoted from the Third Quarterly Report 1956, Malaria Division, are given in the following table (1955 figures in parentheses).

Name of village	Number of examinations	Absolute parasite rate (%)
Ambroben	94	1 (15)
Kimmon	59	8 (24)
Sorido	72	3 (43)

Most probably the infections are old, because *P. malariae* was the only parasite found. In two other villages in Biak a few infections with *P. falciparum* and *P. vivax* were present, but in the adjacent Padaido Islands, *P. malariae* was again the only parasite encountered. These figures give one the impression that malaria in Biak and adjacent islands is nearing extinction. Before spraying malaria was moderately endemic there.

On the other hand preliminary results from the Sarmi district must be mentioned. This is a holo-endemic area along the coast of New Guinea, west of Hollandia. The population is relatively backward. Moreover, they often spend some time in the jungle to collect copal, etc. One year after spraying the results were disappointing. Only slight lowering of the malariometric indices was found, and the number of patients treated for malaria in the hospital and out-patient department remained practically unchanged.

In Hollandia the blood slides of the hospitals and out-patient departments are examined for malaria by the laboratory of the Malaria Division. The place has a floating population, and the actual number

of people living there can only be estimated. It is rapidly extending, and many infected people come from outside. Moreover, housing is often poor, both for Europeans and for Papuans. Nevertheless, the decrease of positive slides, corrected with respect to the increase of population, was about 75% one year after spraying. According to schoolteachers non-attendance at school through malaria had practically disappeared.

In the meantime information about the development of resistance of anophelines against insecticides, noticed in other parts of the world, became more alarming. The phenomenon was no longer observed only in areas where chlorinated hydrocarbons had been used simultaneously as larvicide and as imagicide, but also in areas where they had been applied for the latter purpose only. In Lebanon, *A. sacharovi* developed resistance against DDT (GARRET-JONES & GRAMICCIA, 1954); in Saudia Arabia, *A. stephensi* against DDT; in Nigeria, *A. gambiae* against dieldrin (ELLIOT & RAMAKRISHNA, quoted by WHO, 1955).

This implies that the threat of anophelines becoming resistant to insecticides, is becoming more serious. Whether it is a real threat for New Guinea is not sure. REID & WHARTON (in press, personal communication) are of the opinion that for *A. maculatus* (the main vector in Malaya) the danger of development of resistance is not great. This opinion is founded on the fact that *A. maculatus* is an exophilic anopheline with a low anthropophilic index. The proportion of the anopheline population coming into contact with sprayed walls is only small, and for that reason there is little chance of natural selection for those anophelines which are able to resist insecticides.

Those anopheline species of which resistance has been recorded are, indeed, endophilic (HORSFALL, 1955). The greater part of the population comes in contact with insecticides that kill off the susceptible members of the species, leaving only those able to resist, which then multiply.

Anophelines of the *punctulatus* group take an intermediate position. They are exophilic, but owing to their anthropophily are often compelled to be endophagic, and therefore come into contact with insecticides. However, we have no idea what proportion of the anopheline population live near and in villages. Most probably it is only small, because in New Guinea — an island the size of a small continent — human settlements are sparsely scattered. In between these settlements, a huge anopheline population will, no doubt, support itself on non-human blood. Thus, VAN DIJK (Fourth Quarterly Report 1955, Malaria Division) was attacked by numerous *A. punctulatus* in the Siriwo Valley, far from any human habitation. A similar experience was had by DE ROOK (personal communication) with *A. farauti* in the Lake Valley. It seems not unreasonable to expect that constant intermingling of these jungle mosquitoes with the anopheline population near human settlements may prevent the development of their resistance against insecticides.

A constant watch for indications that resistance to insecticides is

developing will nevertheless be necessary, but the fear of it need not compel the conclusion that insecticide spraying has to be stopped in New Guinea. It is to be hoped that the study of insect physiology on the one hand, and the efforts of the chemical industry on the other, will succeed in finding a definite solution for the problem of resistance to insecticides.

The results of the pilot project in the Lake Area, experiences like those in the Sarmi district, and mathematical calculations (Chapter II) indicate that not every area in New Guinea should be sprayed indiscriminately. In the Fourth Quarterly Report 1955, Malaria Division, some preliminary guiding lines for future policy were drawn in which I pointed out that careful surveys would be necessary to discriminate between areas where the expectations of success of residual spraying are good, and areas where success is less probable. Yard-sticks for this selection are, in the first place, the habits of the human population, because exophilic habits tend to detract greatly from the results. The type of houses is another important factor, because this may vary from strong structures, provided with walls of good quality, to primitive shelters with no walls at all. The species of the *punctulatus* group in the area seems to me of less importance than the human factors, because in New Guinea the latter determine to a great extent the degree of endophagy of the anophelines. The inoculation rate, however, must be estimated during each survey. The fact of transmission being either seasonal or perennial may also be decisive for the ultimate results of residual spraying.

In areas where the expected results will not surpass those of the Sarmi district, spraying had better be postponed. In other areas where residual spraying falls short of complete control, complementary measures may be possible. In urban settlements anti-larval measures of a permanent character (drainage, filling up, etc.) are preferred. For these, close cooperation with the Department of Public Works is necessary. Cooperation with, and good understanding on the part of this department are also necessary for the prevention of man-made breeding places. This is true also for rural areas.

Provision of drugs as a complementary measure of malaria control besides residual spraying is at present much recommended (WHO, 1956 a and c). The intention is to eliminate the parasite reservoir in man in as short a time as possible, after which residual insecticides alone must prevent re-appearance of the disease. Local eruptions can then again be dealt with by drugs. Either 4-amino-quinolines may be used, exerting a strong schizonticidal action, or pyrimethamine, which besides a moderate schizonticidal action, has a sterilizing effect on gametocytes (Shute & Maryon, 1954). Both have the advantage that they can be given at intervals of one or two weeks, and even longer. About ten doses are recommended, to be administered to as many inhabitants of the area as possible.

It is to be feared that it will be extremely difficult to assemble the complete, or even the greater part of the population of Papuan villages several times in succession and at intervals of one or two weeks only. Experiences of FARINAUD & CHOUMARA (1954), however, show that good results could be obtained when only children under 15 years and pregnant women were provided with the drugs. It may therefore not be necessary for the entire population to be actually present when the drugs are distributed. My experience during surveys shows that a large proportion of the children can be assembled, sometimes even all of them. And it is in children that the largest gametocyte reservoir is present. Pilot projects will be necessary to establish the value of this method for New Guinea conditions.

PINOTTI (WHO, 1956 b) mixed chloroquine with cooking salt and observed good suppressive action. Because in New Guinea most natives do not yet obtain their salt from shops, this method does not at present seem very promising for that country.

The choice of insecticide cannot yet be definitely based on information obtained in New Guinea itself. When an emulsion of dieldrin was used in the Nimboran, results were disappointing already 5 months after application, both in the test house and in the field. So far the results with dieldrin wettable powder are more promising. The fact that about nine months after spraying a few anophelines were collected from sprayed walls in the morning need not be thought alarming so long as no survival tests have been made. The infection, at the time, of nine out of fifty six infants could in most cases be attributed to sleeping in the gardens. In several areas of Africa six-month intervals had to be adopted for spraying with dieldrin (WHO, 1956 a). If in New Guinea this interval could be put at eight months, a considerable saving of money and labour would at least be obtained, compared with the six-monthly application of DDT. Together with a higher kill, (which, in the case of dieldrin, compensates better for sitting out of doors in the evening hours by the villagers than in the case of DDT, vide Chapter II), it will make dieldrin wettable powder the formulation of choice for New Guinea.

In conclusion it may be stated that

(a) residual spraying alone does not give the final answer to the malaria problem for the whole of the territory of New Guinea;

(b) that in several restricted areas and in some adjacent islands the possibility of complete interruption of transmission seems to be present;

(c) that, on the other hand, in some backward, and highly malarious regions, where the habit of sleeping outside the villages is prevailing, residual spraying had better be postponed, and

(d) that in other areas new pilot projects, with methods complementary to residual spraying, will be necessary to know whether eradication of malaria can be achieved.

SUMMARY

The fight against malaria with the aid of insecticides with residual action has been carried on since 1945 with success in many countries. There was, however, some difference of opinion among malariologists on the question whether this method would have any chance of success in New Guinea. Those who doubted this pointed to the exophilic habits of the malaria transmitters in the island, which habits would, in their opinion, prevent sufficient contact with insecticides applied to the inner walls of dwellings. Others, on the ground of the results obtained in a few trial experiments, believed that favourable results need not, a priori, be ruled out. A pilot project was therefore indicated. The present thesis describes the pilot project that was made in the neighbourhood of Hollandia in Netherlands New Guinea.

Part of the project consisted of observations of the behaviour of the anopheline vectors and the determination of sporozoite indices; another part of an investigation into the consequences, for these anophelines, of spraying the inner walls of dwellings with insecticides, while, in the third place, the effect was studied which this spraying had on the malariometric indices and the state of health of the population. In addition the investigation provided an opportunity to examine and discuss the classification of malaria in New Guinea.

The principal transmitters of malaria in New Guinea and surrounding islands are three members of the *Anopheles punctulatus* group, namely *A. punctulatus*, *A. farauti*, and *A. koliensis*. Sections performed on 3896 anophelines of this group yielded an average sporozoite index of 1.1 per cent. On the ground of the low sporozoite indices of these mosquitoes, and with the aid of one of the mathematical formulas introduced by MACDONALD, it was concluded that the average duration of life of anophelines of the *punctulatus* group is relatively short. This is a favourable factor with a view to residual spraying.

It was observed that both the time and the manner of catching these anophelines are closely related to the sporozoite index found, the latter being significantly higher in mosquitoes caught on the inner walls in the morning, than in mosquitoes caught on human baits after dark.

A series of observations made in Papuan villages proved that transmission there predominantly occurs indoors.

A. karwari and *A. bancrofti* were found infected with sporozoites in nature for the first time.

The observations of the behaviour of the *punctulatus* group and of *A.*

karwari were partly made in special small experimental houses, constructed after the model of Papuan dwellings, and fitted with window traps. The results of this part of the investigation have already been published (VAN THIEL & METSELAAR, 1954, 1955). They showed that the anophelines in question enter human dwellings to suck blood far more than was generally supposed.

The investigation concerning the effect on the anophelines, of spraying the inner walls of houses was also made in these experimental huts. Part of this investigation, too, has already been communicated by the same authors. One of the huts was treated with DDT wettable powder (2 g DDT per m^2); the other one with a dieldrin emulsion (0.5 g dieldrin per m^2). The results obtained in the DDT house are among the best hitherto published on this subject. A high mosquito mortality was found shortly after spraying, while, six months later, 60 per cent. were still being killed within 24 hours after contact with the insecticide. In the dieldrin house the mortality was practically 100 per cent. the first three months after spraying, decreasing rapidly afterwards. In view of the fact that this decrease is unusual with dieldrin it was attributed to the particular brand that was used.

The study of the effect of residual spraying with DDT on the malariometric indices of a population group took place in villages situated around Sentani Lake, and in small islets in this lake. In this area, two malariologically differential parts could be distinguished, viz. a holo-endemic part, and a part which, though holo-endemic, showed indices corresponding to those of meso-endemic areas. This situation was due to the fact that the latter part comprises the villages on the islets in the lake, where no transmission of malaria occurs. The inhabitants were infected only when they spent the night ashore.

The population of the Nimboran Valley, further west, served at first as an object for comparison with the holo-endemic Sentani area. One year later the Nimboran too became an experimental area, i.e. to ascertain the results of residual spraying with dieldrin.

Before spraying, a determination was made of, inter alia, the spleen rate, the absolute parasite rate, and the heavy-infection rate of the population of the Sentani area. This was repeated one, and again, two, years after spraying. In addition, the children born after spraying were regularly inspected. In the course of the observations, which lasted for two years, it was found that, in the holo-endemic part, the number of infections among these children had fallen by about 90 per cent. as compared with before spraying. Among the population as a whole it was especially the absolute parasite rate and the heavy-infection rate, among the malariometric indices referred to, that showed considerable improvements two years after spraying. The maximum of the absolute parasite rate fell from 85% before, to 45% after, spraying, and shifted from the 2-year-old group to the 6—8-year-old group. The maximum of the heavy-

infection rate fell from 42% to 11%, with the same upward shift. The sporozoite rate of the anophelines fell from 1.2% to 0.2%.

In the meso-endemic part of the area the number of infections among infants decreased by about 65 per cent. The maximum of the vector index fell from 24% to 11%. The heavy-infection index fell only slightly.

Spraying with DDT, therefore, could not completely interrupt the transmission of malaria; but it did diminish it considerably. The relatively slight improvement in the meso-endemic part may be explained by the particular cause of the low endemicity in that part.

Clear indications were obtained showing that the important drops in the malariometric indices were coupled with improvement in the state of health of the population. During the second year after spraying the birth-rate and mortality figures were particularly favourable, especially in the holo-endemic part of the Sentani experimental area. Two years after spraying, moreover, a significant improvement could be observed in the height and weight of some age-groups, as compared with before spraying.

In the Nimboran Valley, observations have been made, so far, for only a short time since spraying with dieldrin wettable powder. Nine months after spraying, 9 out of 56 babies born in that period were found infected with malaria. Here too, therefore, no complete interruption of transmission.

Two reasons are given why transmission in the experimental areas was not entirely interrupted. One is the fact that the inhabitants, instead of spending the night in the villages, now and then remain in the gardens and the sago marshes, where transmission can continue unchecked by insecticides. This cause naturally operates irrespectively of the type of insecticide used. The second reason is that, even in the villages, some degree of transmission is still possible in the evening, when the people remain sitting outside for some time before retiring. But a sufficiently strong insecticide can — within certain limits — compensate for this factor by a higher mortality among the mosquitoes when they come indoors. With the aid of one of MACDONALD's formulas it was possible to calculate that, thanks to this, the latter factor is of very little importance in New Guinea villages sprayed with dieldrin, but that it considerably detracts from the results obtainable in villages treated with DDT.

On the ground of the abovementioned observations, and in view of results achieved with residual spraying in other parts of New Guinea, it is concluded that eradication of malaria in this island exclusively by insecticides with residual action will be possible only in a few favourable areas, but that the chance of success of residual spraying diminishes according as the habit of sleeping outside the villages is more common. In those parts where this habit is general, domestic spraying had better be refrained from for the time being. New pilot projects will be necessary to ascertain whether, and in how far, complementary methods of fighting the disease, in addition to residual spraying, will be capable of nevertheless eradicating

malaria in some districts. One of such methods is the systematic administration, continued for some time, of drugs to the population.

Chapter V discusses the classification of malaria among the population of the Nimboran. It was found that the absolute parasite rate, the heavy-infection rate and the mean positive parasite count of this population fitted into the picture of holo-endemic malaria, as discussed at the Malaria Conference at Kampala (Uganda) in 1950. For the same territory the number of bites by anophelines infected with sporozoites was estimated at 150 per person per year, which, too, corresponds to findings elsewhere in holo-endemic territories. The only index that does not tally is the spleen rate. According to the train of thought underlying the Kampala classification the spleen index in adults in holo-endemic regions is always considerably lower than in children between 2 and 10 years of age. This, however, was found not to be the case in New Guinea. The spleen rate-age curve, therefore, cannot serve as a basis for the classification of malaria endemicity, as in the case of the Kampala classification.

The following are mentioned as possible causes of the difference between the spleen rate of adult Papuans in holo-endemic areas in New Guinea, and that of adults in holo-endemic territories elsewhere: fibrosis of the spleen (for which, however, examination yielded no morphological arguments); natural selection favouring enhanced resistance against malarial infection as a result of centuries of exposure to these infections; sickle-cell anaemia; racial differences; differences in the ratios between the three species of parasites, and nutritional differences.

The large percentage of palpable spleens of malaria-free Papuan infants is discussed.

SAMENVATTING

Malariabestrijding door middel van insecticiden met residuële werking wordt sinds 1945 in vele landen met succes toegepast. Er bestond onder malariologen evenwel verschil van mening of deze methode kans van slagen zou hebben in Nieuw Guinea. Degenen die hieraan twijfelden wezen op de exophiele gewoonten van de malaria-overbrengers van dit eiland, welke, naar hun mening, voldoende contact met op binnenwanden van woningen aangebrachte insecticiden zouden verhinderen. Anderen oordeelden, op grond van de resultaten van enkele oriënterende experimenten, dat gunstige resultaten niet a priori behoefden te worden uitgesloten. Proefprojecten waren dus nodig. Deze dissertatie beschrijft het proefproject dat werd uitgevoerd nabij Hollandia in Nederlands Nieuw Guinea.

Voor een deel bestond het project uit waarnemingen van de gedragingen van de vector-anophelinen en het bepalen van sporozoietenindices, voor een ander deel uit een onderzoek naar de gevolgen voor deze anophelinen van bespuiting met insecticiden van binnenwanden van woningen, terwijl in de derde plaats de invloed van deze bespuiting op de malariometrische indices en de gezondheidstoestand van de bevolking werd nagegaan. Bovendien gaf het onderzoek aanleiding tot beschouwingen betreffende de classificatie van malaria in Nieuw Guinea.

Overbrengers van malaria in Nieuw Guinea en omliggende eilanden zijn hoofdzakelijk drie leden van de *Anopheles punctulatus* groep, namelijk *A. punctulatus, A. farauti* en *A. koliensis.* Als resultaat van secties van 3896 anophelinen van deze groep werd een gemiddelde sporozoietenindex van 1,1% gevonden. Op grond van de lage sporozoietenindices van deze muggen en met behulp van een der door MACDONALD geïntroduceerde mathematische formules, kon tot een betrekkelijk korte gemiddelde levensduur van anophelinen van de *punctulatus* groep worden besloten. Dit is een gunstige factor met het oog op huisbespuiting. Het werd duidelijk dat tijd en wijze van vangen van deze anophelinen grote invloed heeft op de gevonden sporozoietenindex. Deze was namelijk significant hoger bij muggen welke 's morgens binnenshuis op de wanden werden aangetroffen, dan bij muggen 's avonds op mensen gevangen.

Een reeks waarnemingen in Papoea-dorpen maakten duidelijk dat transmissie hier voor het grootste deel binnenshuis plaats vindt.

A. karwari en *A. bancrofti* werden voor het eerst in de natuur met sporozoieten besmet gevonden.

De waarnemingen van gedragingen van anophelinen van de *punctulatus* groep en van *A. karwari* werden voor een deel gedaan in speciale proef-

huisjes, geconstrueerd naar het model van Papoea-woningen en voorzien van raamvallen. De resultaten van dit deel van het onderzoek zijn reeds eerder gepubliceerd (VAN THIEL & METSELAAR, 1954, 1955). Zij toonden aan dat de genoemde anophelinen veel meer binnenshuis komen om bloed te zuigen dan algemeen was aangenomen.

Het onderzoek betreffende de uitwerking van de bespuiting van binnenwanden van huizen op de anophelinen vond eveneens in deze proefhuizen plaats. Van dit onderzoek is een deel der resultaten ook reeds door genoemde auteurs vermeld. Eén der huisjes werd behandeld met DDT wettable powder (2 g DDT per m^2), het andere met een dieldrin emulsie (0.5 g dieldrin per m^2). De resultaten in het DDT huis behoren tot de beste der tot nu toe over dit onderwerp gepubliceerde. Er werd een hoge mortaliteit onder de muggen gevonden kort na de bespuiting, terwijl zes maanden later nog ongeveer 60% was gedood 24 uur na het contact met het insecticide. In het dieldrin huis bedroeg de mortaliteit de eerste drie maanden na de bespuiting practisch 100 per cent, om daarna snel te dalen. Aangezien deze daling ongebruikelijk is voor dieldrin, werd zij aan het gebruikte preparaat toegeschreven.

Het nagaan van de invloed van huisbespuiting met DDT op de malariometrische indices van een bevolkingsgroep vond plaats in dorpen gelegen rondom het Sentani meer en op in dit meer gelegen eilandjes. In dit gebied waren malariologisch twee delen te onderscheiden, namelijk een holo-endemisch deel en een gedeelte, potentieel holo-endemisch, maar met indices overeenkomend met die van meso-endemische gebieden. Deze situatie ontstond doordat dit laatste gebied de dorpen omvat, die op eilandjes in het meer liggen, waar geen transmissie van malaria plaats vindt. De bewoners werden slechts besmet wanneer zij de nacht op de wal doorbrachten.

De bevolking van de meer westelijk gelegen Nimboran vlakte diende aanvankelijk als vergelijkingsobject voor het holo-endemisch Sentani gebied. Een jaar later werd de Nimboran eveneens proefgebied, en wel voor het nagaan van de resultaten van huisbespuiting met dieldrin.

Vóór de bespuiting werden van de bevolking van het Sentani gebied o.a. de miltindex, de parasietendragerindex en de zware-infectieindex bepaald, hetgeen herhaald werd één en twee jaar nà de bespuiting. Bovendien werden regelmatig de kinderen nagezien, welke na de bespuiting geboren waren. Gedurende de twee jaar durende observaties bleek in het holo-endemische deel het aantal infecties onder deze kinderen met ongeveer 90 percent te zijn gedaald, vergeleken met vóór de bespuiting. Onder de gehele bevolking toonden van de genoemde malariometrische indices twee jaar na de bespuiting vooral de parasietendragerindex en de zware-infectieindex belangrijke verbeteringen. Het maximum van de parasietendragerindex daalde van 85% vóór tot 46% nà de bespuiting en verschoof van de groep der 2-jarigen naar die der 6—8-jarigen. Het maximum van de zware-infectieindex daalde van 42% tot 11% en ver-

schoof op dezelfde wijze. De sporozoietenindex van de anophelinen daalde van 1,2% tot 0,2%.

In het meso-endemische deel bedroeg de reductie van het aantal infecties onder zuigelingen ongeveer 65 per cent. Het maximum van de parasietendragerindex daalde van 24% naar 11%; de zware-infectieindex daalde slechts weinig.

De DDT bespuiting kon de malaria-transmissie in het Sentani gebied dus niet volledig onderbreken, wèl belangrijk verminderen. De relatief geringe verbetering in het meso-endemische deel kan verklaard worden door de bijzondere oorzaak van de lage endemiciteit aldaar.

Er werden duidelijke aanwijzingen verkregen dat de belangrijke verlagingen in de malariometrische indices een verbetering van de gezondheidstoestand van de bevolking ten gevolge hadden. De geboorte- en sterftecijfers waren in het tweede jaar na de bespuiting bijzonder gunstig, vooral in het holo-endemische deel van het Sentani proefgebied. Twee jaar na de bespuiting was bovendien in enkele leeftijdsgroepen een significante verbetering van lengte en gewicht waarneembaar, vergeleken met vóór de bespuiting.

In de Nimboran vlakte duren de observaties sinds de bespuiting met dieldrin wettable powder nog slechts kort. Na negen maanden waren negen van de zes en vijftig na de bespuiting geboren zuigelingen besmet met malaria. Ook hier dus geen volledige onderbreking van de transmissie.

Er konden twee oorzaken worden opgegeven waarom transmissie in de proefgebieden niet geheel werd onderbroken. Eén hiervan is dat zo nu en dan bewoners niet in de dorpen overnachten, maar 's nachts in de tuinen en sago-gebieden blijven, waar dan plaatselijk transmissie kan blijven voortgaan, ongehinderd door insecticiden. Deze oorzaak werkt, ongeacht welk insecticide wordt gebruikt. De tweede oorzaak is, dat 's avonds in de dorpen nog enige transmissie mogelijk is, wanneer de bewoners lang buiten blijven zitten. Een sterk dodend insecticide is evenwel — tot zekere grenzen — in staat deze factor te compenseren met hogere mortaliteit onder de muskieten wanneer deze in huis komen. Met behulp van een der door MACDONALD opgestelde formules kon berekend worden dat daardoor deze tweede oorzaak in Nieuw Guinea in met dieldrin bespoten dorpen weinig of geen rol speelt, in met DDT behandelde dorpen evenwel belangrijk afbreuk doet aan de resultaten. Deze berekeningen vonden voorlopige bevestiging in de proefgebieden.

Op grond van bovengenoemde waarnemingen, en naar aanleiding van resultaten elders in Nieuw Guinea met huisbespuiting bereikt, werd geconcludeerd dat eradicatie van malaria uitsluitend met behulp van deze huisbespuiting op dit eiland slechts in enkele gunstige gebieden mogelijk zal zijn, maar dat, naarmate de gewoonte om buiten de dorpen te slapen van meer betekenis is, de kans op succes van huisbespuiting met insecticiden afneemt. In gebieden waar deze gewoonte algemeen is, kan huisbespuiting voorlopig beter achterwege gelaten worden. Nieuwe proef-

projecten zullen nodig zijn om na te gaan óf, en in hoeverre complementaire bestrijdingsmethoden, naast de huisbespuiting, in staat zullen zijn in sommige gebieden toch nog eradicatie te verkrijgen. Eén van deze methoden is het gedurende enige tijd systematisch toedienen van geneesmiddelen aan de bevolking.

In Hoofdstuk V wordt de classificatie van malaria onder de bevolking van de Nimboran besproken. Het bleek dat de parasietendragerindex, zware-infectieindex, en het gemiddelde aantal parasieten bij parasietendragers van deze bevolking pasten in het beeld van holo-endemische malaria, zoals besproken op de Malaria Conferentie te Kampala, Uganda, in 1950. Bovendien kon voor dit gebied het aantal beten van met sporozoieten besmette anophelinen op ruim 150 per persoon per jaar worden geschat, hetgeen eveneens in overeenstemming is met wat elders in holo-endemische gebieden wordt gevonden. De enige index, welke niet overeenstemt, is de miltindex. Volgens de gedachtengang welke aan de Kampala-classificatie ten grondslag ligt, is de miltindex bij volwassenen in holo-endemische gebieden altijd belangrijk lager dan bij kinderen tussen 2 en 10 jaar. Dit bleek evenwel in Nieuw Guinea niet het geval te zijn. De miltindex-leeftijds-curve kan dus niet dienen als basis voor de classificatie van malaria-endemiciteit, zoals bij de voorstellen van de conferentie van Kampala het geval is.

Als mogelijke oorzaken van het verschil tussen de miltindex van volwassen Papoea's in holo-endemische gebieden van Nieuw Guinea en die van volwassenen in holo-endemische gebieden elders, werden genoemd: fibrosis van de milt — waarvoor evenwel bij onderzoek geen morphologische argumenten konden worden gevonden —, natuurlijke selectie in de richting van verhoogde weerstand tegen malariainfecties als gevolg van eeuwenlang blootstaan aan deze infecties, sikkelcel-anaemie, rasverschillen, verschillen in de ratio van de drie parasietensoorten en voedingsverschillen.

Het grote percentage palpabele milten van malaria-vrije Papoea-zuigelingen werd besproken.

REFERENCES

Abbott, W. S. (1925), *J. Econ. Entom., 18,* 265. Quoted by Macdonald & Davidson (1953).

Alfridi, M. K., Singh, J. & Singh, J. H. (1939), *J. Mal. Inst. India., 2,* 219.

Allison, A. C. (1954), *Brit. Med. J., 1,* 290.

—— (1956), *Trans. R. Soc. Trop. Med. Hyg., 50,* 185.

Atchley, F. O., Traylor, W. R. & Weathersbee, A. A. (1955), *J. Parasit., 41,* 273.

Bang, F. B. & Hairston, N. G. (1947), *Am. J. Trop. Med., 27,* 31.

——, Hairston, N. G., Maier, J. & Roberts, F. H. S. (1947), *Trans. R. Soc. Trop. Med. Hyg., 40,* 809.

Barber, M. A., Mandekos, A. & Rice, J. B. (1937), *Am. J. Hyg., 26,* 175.

Barlow, F. & Hadaway, A. B. (1952), *Bull. Entom. Res., 43,* 91.

Beet, E. A. (1947), *East Afr. Med. J., 24,* 212. *Trop. Dis. Bull., 44,* 1091.

Belkin, J. N., Knight, K. L. & Rozeboom, L. E. (1945), *J. Parasit., 31,* 241.

Bertram, D. M. (1950), *Ann. Trop. Med. Parasit., 44,* 242.

Bick, G. H. & Penn, G. H. (1947), *Ann. Entom. Soc. Amer., 40,* 82.

Bierdrager, J. & Rook, H. de, (1954), *Doc. Med. Geogr. Trop., 6,* 252.

Bishop, A. (1955), *Parasit., 45,* 163.

Black, R. H. (1954), *South Pac. Comm., Techn. Papers No. 60 and 61.*

Blackburn, C. R. B. (1948), *Trans. R. Soc. Trop. Med. Hyg., 42,* 117.

Bordas, E., Downs, W. G. & Navarro, L. (1953), *Bull. Wld. Hlth. Org., 9,* 39.

Boyd, M. F. (1940), *Am. J. Trop. Med., 20,* 279.

—— & Stratman-Thomas, W. K. (1933), *Am. J. Hyg., 18,* 485.

Brain, P. (1952), *Brit. Med. J., 2,* 880.

Bray, R. S. & Garnham, P. C. C. (1953), *Brit. Med. J., 1,* 1200.

Bruce-Chwatt, L. J. (1948), *Proc. Fourth Intern. Congr. Trop. Med. Mal., Washington D.C.,* I, 790.

—— (1952), *Ann. Trop. Med. Parasit., 46,* 173.

—— (1954), *Nature, 173,* 353.

—— (1955), *Working Paper WHO/Mal/129.*

—— & Gibson, F. D. (1956), *Trans. R. Soc. Trop. Med. Hyg., 50,* 47.

Brumpt, E. (1949), in *Malariology,* ed. by M. F. Boyd, Philadelphia-London, Saunders, I, 65.

Buck, A. de, (1935), *Ann. Trop. Med. Parasit., 29,* 171.

Busvine, J. R. & Nash, R. (1953), *Bull. Entom. Res., 44,* 371.

Clark, H. C. (1928), *Am. J. Trop. Med., 8,* 423.

Coatney, G. R. & Cooper, W. C. (1948), *Proc. Fourth Intern. Congr. Trop. Med. Mal., Washington D.C.,* I, 629.

——, Cooper, W. C. & Young, M. D. (1950), *J. Nat. Mal. Soc., 9,* 381.

Coggeshall, L. T. (1945), *Am. J. Trop. Med., 25,* 177.

—— & Kumm, H. W. (1937), *J. Exp. Med., 66,* 177.

Colbourne, M. J. & Wright, F. N. (1955), *East Afr. Med. J.,* I, 3 and IV, 161.

—— & Sowah, E. M. A. (1956), *Trans. R. Soc. Trop. Med. Hyg., 50,* 82.

Cooper, W. C., Coatney, G. R. & Ruhe, D. S. (1947), *Am. J. Hyg., 46,* 141.

Crandell, H. A. (1954), *Mosquito News, 14,* 194.

Davey, F. H. & Gordon, R. M. (1933), *Ann. Trop. Med. Parasit., 27,* 27.

Davidson, G. (1953), *Bull. Entom. Res., 44,* 231.

—— (1955), *Trans. R. Soc. Trop. Med. Hyg., 49,* 339.

& Draper, C. C. (1953), *Trans. R. Soc. Trop. Med. Hyg., 47,* 522.

DAGGY, R. H. (1945), *Ann. Entom. Soc. Amer., 38,* 1. *Rev. Appl. Entom., 34,* 122.
DELIYANNIS, G. A. & TAVLARAKIS, N. (1955), *Brit. Med. J., 2,* 301.
DOORENBOS, S. B. (1931), *Geneesk. Tijdschr. v. Ned.-Indië, 71,* 1458.
DOWNS, W. G. & BORDAS, E. (1951), *Am. J. Hyg., 54,* 150.
——, BORDAS, E. & NAVARRO, L. (1951), *Science, Sept. 7,* 258.
ESSED, W. F. R. (1925), *Meded. Dienst Volksgezondh. Ned.-Indië, 14,* 298.
FABIANI, G. & ORFILA, J. (1954), *C.R. Soc. Biol., 148,* 1239.
FAIRLEY, N. H. (1945), *Trans. R. Soc. Trop. Med. Hyg., 38,* 311.
FARINAUD, M. E. & CHOUMARA, R. (1954), *Bull. Wld. Hlth. Org., 11,* 793.
FERRY, R. J. (1956), *Trans. R. Soc. Trop. Med. Hyg., 50,* 47.
FORD, E. (1950), *Med. J. Austr., 1,* 749.
GARNHAM, P. C. C. (1949), *Ann. Trop. Med. Parasit., 43,* 47.
GARRETT-JONES, C. & GRAMICCIA, G. (1954), *Bull. Wld. Hlth. Org., 11,* 865.
GATER, B. A. R. (1935), *Aids to the Identification of Anopheline Imagines in Malaya.* Malaria Adv. Board F.M.S., Singapore.
GEORGOPOULUS, G. D. (1954), *Bull. Wld. Hlth. Org., 11,* 855.
GIGLIOLI, G. (1949), *Brit. Med. J., 2,* 595.
GILLIES, M. T. (1955), *Am. J. Trop. Med. Hyg., 4,* 1103.
GILROY, A. B. (1951), *Ind. J. Mal., 5,* 171.
GOOR, W. Th. VAN, LODENS, J. G. & GOMEZ, J. A. (1950), *Doc. Neerl. Indon. Morb. Trop., 2,* 341.
GORDON, H. H., LIPPINCOTT, S. W., MARBLE, A., BALL, A. L., ELLERBROOK, L. D. & GLASS, W. W. (1945), *Arch. Intern. Med., 75,* 159. *Trop. Dis. Bull., 42,* 692.
HACKET, L. W. (1941), in *A Symposion on Human Malaria.* Am. Ass. Advanc. Science. p. 148.
HADAWAY, A. B. & BARLOW, F. (1951), *Bull. Entom. Res., 41,* 603.
HELL, J. C. VAN, (1952), *Doc. Med. Geogr. Trop., 4,* 45.
HEYDON, G. A. M. (1923), *Med. J. Austr., 15 Dec. 1923.*
HIMPE, N. E. & PIERQUIN, L. (1950), *Ann. Soc. Belge Med. Trop., 30,* 217.
HODGKIN, E. P. (1950), *Trans. R. Soc. Trop. Med. Hyg., 43,* 617.
HOEVEN, J. A. VAN DER, (1956), *Resultaten van een Onderzoek naar Voeding en Deficientie-Verschijnselen bij Autochthone Zuigelingen in Nederlands Nieuw Guinea.* Thesis. Utrecht.
HORSFALL, W. R. (1955), *Mosquitoes.* New York, Ronald Press Co.
—— & PORTER, D. A. (1947), *Ann. Entom. Soc. Amer., 39,* 549.
IYENGAR, M. O. T. (1932), *Ind. J. Med. Research, 20,* 841.
JAMES, S. P. (1931), *Trans. R. Soc. Trop. Med. Hyg., 24,* 5.
JELLIFFE, D. B. & ONWUMERE, R. E. (1953), *J. Trop. Med. Hyg., 56,* 187.
KENNEDY, J. S. (1947), *Bull. Entom. Res., 37,* 593.
KING, W. V. (1949), in *Malariology,* ed. by M. F. BOYD, Philadelphia-London, Saunders, I, 506.
—— & HOOGSTRAAL, H. (1946), *J. Nat. Mal. Soc., 5,* 153.
KLIGLER, I. J. & MER, G. (1937), *Ann. Trop. Med. Parasit., 31,* 71.
KNIGHT, K. L. & FARNER, D. S. (1944), *Proc. Entom. Soc. Wash., 46,* 132.
LAIRD, M. (1946 a), *Trans. R. Soc. New Zealand, 75,* 465.
—— (1946 b), *Trans. R. Soc. New Zealand, 76,* 148.
LAMBERT, S. M. (1949), in *Malariology,* ed. by M. F. BOYD, Philadelphia-London, Saunders, II, 820.
LAMPRELL, B. A. (1936), *Rec. Mal. Surv. India, 6,* 213.
LEHMAN, H. & CUTBUSH, M. (1952), *Brit. Med. J., 1,* 404.
LUYKEN, R. & LUYKEN-KONING, F. W. M. (1956), *Doc. Med. Geogr. Trop., 8,* 45.
MACDONALD, G. (1950 a), *Trop. Dis. Bull., 47,* 907.
—— (1950 b), *Trop. Dis. Bull., 47,* 915.
—— (1952 a), *Trop. Dis. Bull., 49,* 569.
—— (1952 b), *Trop. Dis. Bull., 49,* 813.
—— (1952 c), *Trans. R. Soc. Trop. Med. Hyg., 46,* 227.

—— (1955), *Trans. R. Soc. Med., 48,* 295.
—— & DAVIDSON, G. (1953), *Bull. Wld. Hlth. Org., 9,* 785.
MACKERRAS, I. M. (1947), *Med. J. Austr., 1,* 1.
—— & ABERDEEN, J. E. C. (1946), *Med. J. Austr., 2,* 763.
MACKERRAS, M. J. & ERCOLE, Q. N. (1948 a), *Austr. J. Exp. Biol. Med. Science, 26,* 439.
—— & —— (1948 b), *Austr. J. Exp. Biol. Med. Science, 26,* 515.
—— & ROBERTS, F. H. S. (1947), *Ann. Trop. Med. Parasit., 41,* 329.
MAEGRAITH, B. G., DEEGAN, T. & SHERWOOD JONES, E. (1952), *Brit. Med. J., 2,* 1382.
MANALANG, C. (1928), *Philip. J. Science, 37,* 123. Quoted in Boyd's *Malariology,* p. 672.
MASSEQUIN, A. & POLINACCI, A. (1953), *Bull. Soc. Path. Exot., 46,* 673.
MCARTHUR, J. (1947), *Trans. R. Soc. Trop. Med. Hyg., 40,* 537.
MAUZÉ, J. (1946), *Medicine Trop., 6,* 109.
METCALF, A. S., HESS, A. D., SMITH, G. E., JEFFERY, G. M. & LUDWIG, G. W. (1945), *Public Hlth. Reports, 60,* 753.
METSELAAR, D. (1955), *Doc. Med. Geogr. Trop., 7,* 193.
—— (1957), *Bull. Wld. Hlth. Org.,* in press.
MILLER, M. J. (1954 a), *Am. J. Trop. Med. Hyg., 3,* 458.
—— (1954 b), *Am. J. Trop. Med. Hyg., 3,* 825.
MORIN, H. G. S. (1955), *Bull. Soc. Path. Exot., 48,* 333.
MUIRHEAD-THOMSON, R. C. (1950), *Trans. R. Soc. Trop. Med. Hyg., 43,* 401.
—— (1951 a), *Brit. Med. J., 1,* 1114.
—— (1951), *Mosquito Behaviour.* London, Arnold & Co., p. 33.
NAIR, C. P. (1947), *Med. J. Malaya, 8,* 3.
OOMEN, H. A. P. C. & MALCOLM, S. H. (1956), *Nutrition and the Papuan Child, Report,* South Pacif. Comm.
OWEN, W. B. (1945), *J. Parasit., 31,* 236.
PERRY, W. J. (1946), *J. Nat. Mal. Soc., 5,* 127.
—— (1949), *Am. J. Trop. Med., 29,* 747.
RAMSEY, G. C., CHANDRA, S. N. & LAMPRELL, B. A. (1936), *Rec. Mal. Surv. India, 6,* 49.
RAPER, A. B. (1955), *Brit. Med. J., 1,* 1186.
REEVES, W. C. & RUDNICK, A. (1951), *Am. J. Trop. Med., 31,* 633.
ROBERTS, F. H. S. (1943), *Austr. J. Exp. Biol. Med. Science, 21,* 259.
—— & O'SULLIVAN, P. J. (1948), *Bull. Entom. Res., 39,* 159.
ROBERTS, O. J. (1954) *Parasit., 44,* 438.
ROOK, H. DE, (1924), *Geneesk. Tijdschr. v. Ned.-Indië, 44,* 642.
—— (1929), *Malaria en Anophelinen aan de Boven-Digoel, Report,* 1929 (unpubl.).
—— (1938), in *Nieuw Guinee,* ed. by W. C. KLEIN, Amsterdam, Molukken Inst., de Bussy, p. 856.
—— (1949), *Doc. Neerl. Indon. Morb. Trop., 1,* 160.
—— (1950), *Rapport omtrent een Bezoek aan Hollandia* (unpubl.).
—— (1954), *The appearance of A. subpictus in Biak.* Second Asian Malaria Conference.
ROZEBOOM, L. E. & KNIGHT, K. L. (1946), *J. Parasit., 32,* 95
RUSSELL, P. F. (1935), *Am. J. Trop. Med., 15,* 11.
—— & JACOB, V. P. (1939), *J. Mal. Inst. India., 2,* 131.
ROTTER, W. & BÜNGELER, W. (1955) in *Lehrbuch der Speciellen Pathol. Anat.* ed. by E. KAUFMANN. De Gruyter & Co., 11e und 12e Auflage.
SCHÜFFNER, W. (1919), *Geneesk. Tijdschr. v. Ned.-Indië, 59,* 219.
—— & HYLKEMA, B. (1921), *Meded. Burg. Geneesk. Dienst Ned.-Indië, 10,* 48.
SCHWINK, TH. M. (1954), *Am. J. Trop. Med. Hyg., 3,* 232.
SENIOR-WHITE, R. (1954), *Nature, 173,* 730.
SHUTE, P. G. & MARYON, M. (1954), *Trans. R. Soc. Trop. Med. Hyg., 48,* 50.
SINGH, J. & RAY, A. P. (1952), *Ind. J. Mal., 6,* 449.
SINTON, J. A. & MULLIGAN, H. W. (1933), *Rec. Mal. Surv. India, 3,* 381 and 719.
SPICER, S. S. (1945), *J. Nat. Mal. Soc., 4,* 165.
SWELLENGREBEL, N. H. (1948 a), *Proc. Fourth Intern. Congr. Trop. Med. Mal., Washington D.C.,* I, 789.

—— (1948 b), *Ibid.*, II, 1563.
—— (1949), *Doc. Neerl. Indon. Morb. Trop., 1,* 165.
—— (1950), *Ann. Trop. Med. Parasit., 44,* 84.
——, SCHÜFFNER, W. & SWELLENGREBEL-DE GRAAF, J. M. H. (1919), *Meded. Burg. Geneesk. Dienst Ned.-Indië, 8,* 1.
—— & STACK, TH. (1949), *Ann. Soc. Belge Med. Trop., 29,* 207.
—— & SWELLENGREBEL, J. M. H. (1948), *Ned. Tijdschr. v. Geneesk., 92,* 3498.
SWINDLER, D. R. (1955), *Human Biol., 27,* 284.
THIEL, P. H. VAN, & METSELAAR, D. (1954), *Bull. Wld. Hlth. Org., 11,* 521.
—— & —— (1955), *Doc. Med. Geogr. Trop., 7,* 164.
—— & WINOTO, R. M. P. (1951), *Doc. Neerl. Indon. Morb. Trop. 3,* 295.
TIEL, N. VAN, (1952), *Bull. Entom. Res., 43,* 187.
TOFFALETTI, J. P. & KING, W. V. (1946), *J. Nat. Mal. Soc., 6,* 32.
TRAPIDO, H. (1946), *Am. J. Trop. Med., 26,* 383.
TROWELL, H. C. (1949), *Trans. R. Soc. Trop. Med. Hyg., 42,* 417.
VISWANATHAN, D. K. (1951 a), *Ind. J. Mal., 5,* 251.
—— (1951 b), *Ibid., 5,* 271.
WALCH, E. W. & SARDJITO, M. (1928), *Meded. Dienst Volksgez. Ned.-Indië, 17,* 234.
WHARTON, R. H. (1951 a), *Bull. Entom. Res., 42,* 1.
—— (1951 b), *Nature, 167,* 854.
—— (1955), *Bull. Entom. Res., 46,* 301.
WHO. (1951), *Technical Report Series No. 38.*
—— (1955), *Mal/Inf/8.*
—— (1956 a), *Second Afr. Mal. Conf., Mal/160/1956.*
—— (1956 b), *Mal/Inf/15.*
—— (1956 c), *Technical Report Series No. 103. Second Asian Malaria Conference.*
WILKINSON, P. R. (1951), *Bull. Entom. Res., 42,* 45.
WILSON, D. B. (1936), *Trans. R. Soc. Trop. Med. Hyg., 29,* 583.
—— (1938), *Acta Conv. Tertii de Tropicis atque Malariae Morbis,* Amsterdam, II, 346.
—— & WILSON, M. E., (1937), *Trans. R. Soc. Trop. Med. Hyg., 30,* 431.
——, GARNHAM, P. C. C. & SWELLENGREBEL, N. H. (1950), *Trop. Dis. Bull., 47,* 677.
WOODHILL, A. R. (1946), *Proc. Linnean Soc. New South Wales, 70,* 276.
WOODRUFF, A. W. (1956), *Trans. R. Soc. Trop. Med. Hyg., 50,* 197.
YOUNG, M. D., EYLES, D. E. & BURGESS, R. W. (1948), *J. Nat. Mal. Soc., 7,* 171.
——, EYLES, D. E., BURGESS, R. W. & JEFFERY, G. M. (1955), *J. Parasit., 41,* 315.
YUST, H. R. (1947), *J. Econ. Entom., 40,* 762.